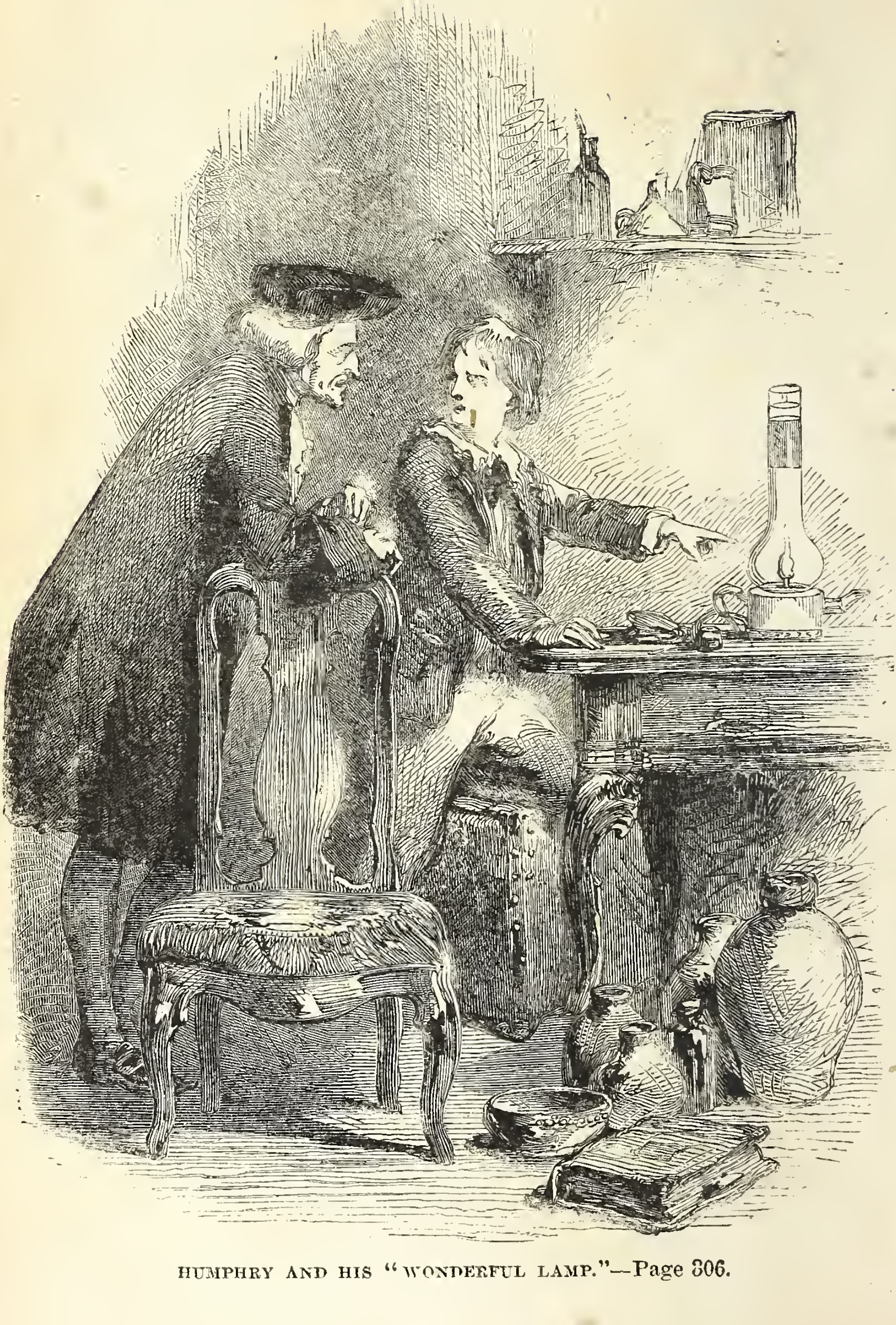
J. M. Randall
Lebanon
Ills
1872.



HUMPHRY AND HIS "WONDERFUL LAMP."—Page 306.

THE

WONDERS OF SCIENCE;

OR,

YOUNG HUMPHRY DAVY

(THE CORNISH APOTHECARY'S BOY, WHO TAUGHT HIMSELF NATURAL PHILOSOPHY, AND EVENTUALLY BECAME PRESIDENT OF THE ROYAL SOCIETY).

The Life of a Wonderful Boy

WRITTEN FOR BOYS.

BY

* HENRY MAYHEW, Born. London 1812

AUTHOR OF "THE STORY OF THE PEASANT-BOY PHILOSOPHER," ETC.

"Majestic steep! ah, yet I love,
With many a lingering step to rove,
Thy ivied rocks among;
Thy ivied, wave-beat rocks recall
The former pleasures of my soul,
When life was gay and young.

Enthusiasm—Nature's child—
Here sung to me her wood-songs wild,
All warm with native fire;
I felt her soul-awakening flame,
It bade my bosom burn for fame,
It bade me strike the lyre."

DAVY'S *Ode to St. Michael's Mount in Cornwall.* Written at the age of 18.

NEW YORK:

HARPER & BROTHERS, PUBLISHERS,

PEARL STREET, FRANKLIN SQUARE.

1856.

* Biographical Sketch in Beeton's Dict. London 1860

A WORD OR TWO

BY WAY OF

EXPLANATION AND DEDICATION

TO

MICHAEL FARADAY.

My dear Sir,—

I inscribe your name on one of the fly-leaves of this little book, with the same devotion as youths are wont to carve upon the trunk of some forest tree the name of those whom they admire most in the world; and I do so for many reasons.

First of all, because Davy was, as it were, the foster-father of your great genius; and, secondly, because it allows me to tell the lads for whom this book has been written the graceful story of the way in which the hero of it first befriended you—the young "bookseller's apprentice, very fond of experiment, and very averse to trade"—in your own dignified language; and, moreover, because I know your zeal in the cause of education, and that you are, like all generous minds when fired with the beauty of fine truths and discoveries, unable to rest, as it were, till you have imparted them to others, and so made them as happy as yourself with the wondrous knowledge. Indeed, it is the glorious privilege of intellectual pursuits that they are not marked by that "selfishness," which made you as a boy "desirous of escaping from trade;" for wisdom, happily, can share its riches with the world, and yet be all the richer for the sharing. None know better than yourself that every science is built up of an infinity of such contributions; and that, had the human mind been impressed with a desire to hoard its intellectual gains—to keep them locked in the coffers of the brain—how little even *you*—who have added, by your many profound discoveries, more to the knowledge-fund of the world than any other single philosopher—could yourself have known. There is no finer instance, perhaps, of human magnanimity than the chemist working unseen in his laboratory—watching alone for hours the action of different kinds of so-called dead matter upon each other, in the hope of being able to add his little mite of truth to that store of mental riches, which is to benefit not only his own generation, but all those to come for ages after. Nor can we detract from the natural greatness of the act by ascribing it to any lower principle of our soul—such as that petty craving for praise which we call "vanity" in women, and a desire for fame among poets and philosophers; for every true scientific mind knows that there is sufficient reward in the intense beauty of a new discovery—the first flash across the brain of some deep insight into the mysteries of Nature—to repay him, over and over again, for all the long puzzling of his thoughts; and that, were he even alone in the world, without a voice to cheer him on, he must still continue spelling out passage after passage of the Great Poem of Creation, from the mere love of the Poem itself.

I can readily understand that it was some such generous purpose that first rendered you anxious "to enter the service of science, which," as you say, you "imagined made its pursuers amiable and liberal," for this is impressed in every line of the following letter, which becomes peculiarly interesting as a record of the circumstances which brought together two of the greatest chemical geniuses that the world has yet seen.

"To J. A. Paris, M.D.

"Royal Institution, *Dec.* 23, 1829.

"My dear Sir,—You asked me to give you an account of my first introduction to Sir H. Davy, which I am very happy to do, as I think the circumstance will bear testimony to his goodness of heart.

"When I was a bookseller's apprentice, I was very fond of experiment, and very averse to trade. It happened that a gentleman, a member of the

Royal Institution, took me to hear some of Sir H. Davy's last lectures in Albemarle Street. I took notes, and afterwards wrote them out more fairly in a quarto volume.

"My desire to escape from trade, which I thought vicious and selfish, and to enter into the service of Science, which I imagined made its pursuers amiable and liberal, induced me at last to take the bold and simple step of writing to Sir H. Davy, expressing my wishes, and a hope that, if an opportunity came in his way, he would favour my views; at the same time, I sent the notes I had taken at his lectures.

"The answer, which makes all the point of my communication, I send you in the original, requesting you to take great care of it, and to let me have it back, for you may imagine how much I value it.

"You will observe that this took place at the end of the year 1812, and early in 1813 he requested to see me, and told me of the situation of Assistant in the Laboratory of the Royal Institution, then just vacant.

"At the same time that he thus gratified my desires as to scientific employment, he still advised me not to give up the prospects I had before me, telling me that Science was a harsh mistress; and, in a pecuniary point of view, but poorly rewarding those who devoted themselves to her service. He smiled at my notion of the superior moral feelings of philosophic men, and said he would leave me to the experience of a few years to set me right on the matter.

"Finally, through his good efforts, I went to the Royal Institution early in March of 1813, as Assistant in the Laboratory; and in October of the same year went with him abroad, as his assistant in experiments and in writing. I returned with him in April, 1815, resumed my station in the Royal Institution, and have, as you know, ever since remained there.

"I am, dear Sir, very truly yours,

"M. FARADAY."

The following is the note of Sir H. Davy, alluded to in Mr. Faraday's letter:

"TO MR. FARADAY.

"*December* 24, 1812.

"SIR,—I am far from displeased with the proof you have given me of your confidence, and which displays great zeal, power of memory, and attention. I am obliged to go out of town, and shall not be settled in town till the end of January: I will then see you at any time you wish.

"It would gratify me to be of any service to you. I wish it may be in my power.

"I am, Sir, your obedient, humble servant,

"H. DAVY."*

And now let me add, by way of excuse for the many short-comings of the present volume, that I

* Extracted from Dr. Paris's "Life of Davy."

have found some little difficulty in developing my object, which was to show youths how one of the greatest natural philosophers had, when a lad, like themselves, *made himself* acquainted with the principles of science, and thus to induce them to "go and do likewise;" for, assuredly, there is no education like that self-education which is sure to follow directly a fervent taste is created for any particular branch of knowledge. To create such a taste was my sole motive for writing this book. Nevertheless, when I came to deal with the subject, I discovered that it was impossible to follow *literally* the scientific history of Davy's mind, since he had begun by adopting the most flighty theories. To have evolved all his visionary notions when a lad, in a work that was meant to have an educational tendency, would have been merely to have taught error. I have, however, in adapting the book to the present state of science, deviated as little as possible from the biographical facts, and I have, moreover, in all things striven to be true to the character of my hero, which after all is the great truth required in "story-books." Again, by a pardonable license, I believe I have made the boy foreshadow some of his after-discoveries—such as the safety-lamp—and for all these deviations I can only plead a desire to show youths that they have it in their own power to do as the Cornish apothecary's boy did, if they will but set about the work quickened with the same determination to succeed.

It is my belief that our present system of education begets in the minds of youths too great a sense of dependence, and too little reliance on their own powers, so that it is thought by a lad on leaving school to be impossible to learn any thing without the help of a master to teach it. Now my object in such books as the present is to show boys that some of the greatest minds the world has yet seen have been self-taught; and by letting the young note how the great men, when *they* were young too, set about the task of informing themselves, thus to breed in youthful minds not only a faith in their own capabilities, but a taste for the beauties of knowledge, as well as a strong purpose to number themselves, if possible, among the future teachers of mankind.

And now, my dear Sir, let me, in conclusion, thank you for your generous encouragement of my labours when I was engaged in inquiring into the condition of the "*London Poor.*" Many know your wisdom, but none are better acquainted with your goodness than

Yours, very truly,

HENRY MAYHEW.

BONN, *Nov. 25th*, 1854.

CONTENTS.

THE WONDERS OF SCIENCE.

CHAPTER I.

THE WIDOWED AND THE FATHERLESS.

"WELL, gentlemen, I have gone over your several accounts, and find that the debts of the late Mr. Robert Davy amount altogether to the sum of £1300."

These words were addressed to a little group of tradesmen and others who were assembled in a small room over a mercer's shop, in the town of Penzance. There was Jan Penberthy, the neighbouring miller, who, though in his holiday clothes, had sufficient of the flour clinging to his black eyebrows and whiskers to indicate his calling; and Malachy Carteret, the carpenter and builder, who had slipped on his best coat, as he ran out from his work, to be present at the meeting, and had still the brass ends of his foot-rule projecting from the little fob at the side of his fustian trousers. There was Mr. Trevisky, too, the sporting lawyer, in his check shooting-jacket, all over pockets, and those at the hips large enough for game or law papers, and who held in his hand a square, horny-looking parchment deed; and close beside him sat the village apothecary, in a long, snuff-brown great-coat, between the skirts of which might be seen, shining in the light, his high boots, that reached well up to his knees; and there were two or three other of the village tradespeople besides, all seated at the end of the little apartment, and who, when they heard the amount of their united claims, exchanged glances with one another in astonishment at the largeness of the sum.

At a table in front of the little assembly sat Mr. John Tonkin, the old gentleman who had addressed them. Nor was he the least remarkable among the company, for he was habited in the costume that had been fashionable in the previous century. Over his shrivelled and veiny hands flapped deep lace-ruffles, and the top of his head was white as a twelfth-cake, with the large powdered wig that surmounted it. The straight, stand-up collar of his Quaker-cut coat was as if mildewed at the back with the powder that fell from his peruke, and the large fan-like frill that protruded from his waistcoat—which was long as a modern groom's—was speckled brown in places with snuff, as thick as nutmeg on a custard; while from underneath the table at which he sat peeped a pair of gold shoe-buckles and black silk stockings. On a chair by his side lay the cocked hat which completed his antiquated costume, and the underneath part of which was greyed with hair-powder and long usage.

Peculiar as was the old gentleman's dress, yet it had more of a quaint than comical appearance with him; for his features, though creased with age, and his form, though slightly bowed with his load of years, were still of too manly a cast to excite any irreverent feeling, even in the lightest minds; indeed, he had too stern and austere a look to dispose any to smile at the oddity of his costume.*

* Mr. Tonkin (says Dr. John Davy, in his Memoirs of the Life of his brother) "will long be remembered in Penzance, both for excellences and peculiarities. The latter marked him as a person of the gone-by time, and attracted the notice even of the careless observer. He held in aversion modern changes of fashion, and in his old age wore the dress of his youth—the cocked hat, large powdered wig, hand-ruffles, upright collar; in brief, the professional dress of the beginning of the last century —and his manly form and countenance suited well with this venerable costume." Dr. Davy says, moreover, that Mr. Tonkin "held a distinguished place among his fellow-townsmen, being looked up to for his sterling worth and strength of judgment, and very dear to his friends for his benevolence, kindness, and very generous and friendly disposition." He was "of a quick temper," he adds, "but his anger was of short duration."—See *Life of Sir Humphry Davy*, vol. i. p. 109.

Sir Humphry himself, in his last letter to Mr. Tonkin, says, "If I was nearer I would endeavour to be useful to you. I would endeavour to pay some of the debts of gratitude I owe to you, *my first protector and earliest friend.* As it is, I must look forward to a futurity that will enable me to do this; but believe me, wherever I am, and whatever may be my situation, I shall never lose the remembrance of obligations conferred on me, or the sense of gratitude which ought to accompany them."

After a short pause the old gentleman continued his address to the company before him. "Now to meet this sum of £1300 there is the property of the farm at Varfell, which is valued at about £150 a year, and upon which Mr. Trevisky's client has a mortgage to a small amount."*

At the mention of the name of the attorney, that gentleman proceeded to open the square deed before him, and to throw back the huge skins, that looked like large sheets of bladder, as he glanced his eye down them one after another.

"This little property, gentlemen," proceeded Mr. Tonkin, "is all that the widow and her five children—the eldest of whom, you will permit me to remind you, is but sixteen years of age—have to subsist upon. Mrs. Davy, therefore, I think, has a claim to some little indulgence and sympathy at your hands. Some years must pass before her children are old enough to obtain a maintenance for themselves, and in the mean time they have to be supported, educated, and apprenticed. How this is all to be done upon such slender means is a matter that I need not tell you adds severely to the widow's distress; for not only has she the grief to bear on losing the partner with whom she had lived

* "When Mrs. Davy became a widow, she was in her thirty-fourth year, with five children, all of whom were still to be educated, excepting Humphry, her eldest son. Her income at this time was about £150 a year, and it was encumbered with a debt of £1300."—*Dr. Davy's Life of Sir Humphry*, vol. i. p. 7.

in happiness for nearly twenty years, but she has the greater grief, if possible, of knowing that her children are fatherless, and that she herself lacks the means of providing for them in comfort. Her sorrow, then, gentlemen, has a double sting. It arises not only from regret for the past, but a dread of the future. I am sure, therefore, she will, under her great affliction, meet with every consideration from you."

At this point Mr. Malachy Carteret—a little man, remarkable for the blackness and bushiness of his eyebrows, which grew so close together as to look like one long one, rather than a pair, and who, from his being considered a "good prayer-maker" at the chapel to which he belonged, was always glad of an opportunity of displaying his oratorical powers—ventured to observe, that he was sure all then present felt for Mrs. Davy under her trials, but they had most of them children of their own, and it was their duty to look at home first; for who could tell how soon they themselves might be called away, and their little ones left in the same distressing situation, unless their bills were duly paid? "Now my little account," proceeded the carpenter, "has been standing so long as the new house at Varfell has been built, and that were the same year as Dolly Pentreath died—I mean her as were 102 year old—and that's some time agone, you know; so I'm sure no one can't say as I've been hard about my little matter. But we were a thinking among ourselves, Mr. Tonkin, that as you'd always been suchy kind friend to the family, and as we hadn't no wish to trouble Mrs. Davy under her affliction, that maybe a—a—you—you—you wudn't mind becoming security yourself for the debts, and then they cud stand over for another year or two if need be. You'll excuse ma making maself so bould, sir; but I'm a plain man, and think plain speaking is better than double-dealing at ale times."

The old gentleman's brow fell suddenly, and looking the carpenter full in the face, he said, scornfully, "Though you have no wish to trouble Mrs. Davy under her afflictions, you would not object, it seems, to involve her friends in her liabilities. You allude, sir, to my past services, and surely the recollection of the melancholy occasion which rendered such services necessary should have made you less eager after what is due to you, and less anxious to entangle in the family difficulties a person who, when he found that his assistance was needed, has never added to the distress by waiting till asked for it. In this very house, now thirty-seven years ago, it was my sad lot to see three young girls deprived of both father and mother in the same week. Mrs. Davy was one, and the youngest of those three—left almost in her infancy without a friend or counsellor to help her through the world. And now in her womanhood the same hard fate attends her—bereft of him whose affection had made him her protector, and finding her children fatherless, as she herself was, at the very time when needing most a father's care. Surely the remembrance of a double bereavement like this, sir—for hardly is she out of her orphanage before she is doomed to enter on her widowhood—should teach you that Providence must have some special design in visiting so much misery upon this poor lady.* Nevertheless, I am happy to say that Mrs. Davy needs no pecuniary assistance from her friends, and requires but little indulgence from those to whom her husband was indebted. It is proposed to increase the mortgage upon the farm at Varfell to the amount of £1300, though this—

* "Mrs. Davy was the third and youngest daughter of Grace and Humphry Millett. . . . . Mr. Millett was engaged in business in the town of Penzance as a mercer. He and his wife died young, *and in the same week*—he on the 3d of June, 1757, and she on the 9th. . . . . Mr. John Tonkin was their friend, and supplied the place of a father to them (the orphan children), and they retained through life a most grateful sense of his kindness, and of the great obligations they owed to him. At the time of the death of Mr. and Mrs. Millett, he (Mr. Tonkin) was residing in their house (I suppose in lodgings), and there he continued to reside for some years, the children being under the care of a Miss Peggy Adams, their cousin, in whose name the mercer's business was continued, by the profits of which the family was chiefly supported."—*Dr. John Davy*, p. 7, vol. i.

Dr. Paris, in his life of Sir Humphry Davy (p. 2), says, speaking of the philosopher's mother, "Her maiden name was Grace Millett, and she was remarkable for the placidity of her temper and the amiable and benevolent tendency of her disposition.

even if Mr. Trevisky can obtain the money at 4 per cent.—will reduce the family income to less than £100 a year; and immediately the mortgage is completed and the money paid, your accounts, gentlemen, will be discharged. The reason of my requesting your attendance here to-day was not to seek to make any compromise with you, nor to crave any unusual indulgence at your hand, but merely to ascertain the amount of the collected claims against the late Mr. Davy, and to inform you that steps were being taken for a speedy payment of them, so that you might not trouble his widow with any importunities on the matter. She, poor soul, has enough to bear with in the privation she has recently suffered, and those wordly ones

She had been adopted and brought up with her two sisters, under circumstances of affecting interest, by Mr. John Tonkin. . . . To withhold a narrative of the circumstances which led Mr. Tonkin to the adoption of these orphan children would be to deprive the world of one of those bright examples of pure and disinterested benevolence which cheer the heart and ornament our nature. . . . . The parents of these children having been attacked by a fatal fever expired within a few hours of each other. The dying agonies of the surviving mother were sharpened by her reflecting on the forlorn condition in which her children would be left. For, although the Milletts were originally aristocratic and wealthy, the property had undergone so many subdivisions as to have left but a very slender provision for the member of the family to whom she had united herself." On the decease of Mrs. Millett (Dr. Paris tells us), Mr. Tonkin immediately took charge of her three orphan daughters, and "continued their kind benefactor until each in succession found a home by marriage."

which threaten herself and children in the future; but, thank Heaven, she is prepared to meet all her trials with resignation and courage."

Then, rising from his seat, he bowed haughtily to the company as he said, "Now, gentlemen, I wish you a good day."

The words were no sooner uttered than Mr. Trevisky, who had previously folded up the deed, and sat fidgetting on his chair for the last quarter of an hour—now twisting a piece of red tape round and round—then paring his nails—and then twiddling the brass fox's-head buttons of his shooting-jacket—the words were no sooner uttered, we repeat, than the lawyer started to his feet, and, pulling out his watch, said, half to himself, "Egad, I shall be in time for the cock-fight yet;" and then, waving his hand rapidly in the air, shouted as he darted from the room, "I'll see to that directly, Mr. Tonkin—I'll see to it directly."

Malachy Carteret was the last to leave, for he purposely remained behind to plead his excuse to Mr. Tonkin for the use he had made of his name.

"I hope no offence, I'm sure, sir," began the little carpenter. "I always thoft ma money safe enow, but ya see times is hard, and there's the men to pay every Saturday night, and that's a great pull. No one feels more for Mrs. Davy than your humble servant M. C. does. Her husband always behaved honourable to me, and M. C. is 'ever grateful for past favours,' as my card says. That there wor a bit of poor Mr. Davy's handiwork, worn't it, Mr. Tonkin?" added Malachy, pointing to the oak mantel-piece, that was elaborately and beautifully carved with birds, fruit, and flowers.

"Yes," returned the old gentleman, dryly: "Mr. Davy presented it to me when he used to come courting here, at the time his wife and her sisters were under my care."

"Ah, he wor very clever with his tools," continued the carpenter. "'The last of the carvers,' we used to call him. I remember him afore he went to London to larn the business—he lived with his uncle Robert then. I used to work for the uncle; indeed I sarved my time with the late Mr. Davy's father—the builder, ya know—so, of coose, I cudn't mean anything but kindly to the family—only money's very scarce just now, sir, and I've a-mashes of bills to meet this quarter: so I hope no offence, I hope no offence, sir. You doan't want nothing in my way, do you, Mr. Tonkin?"

The old gentleman shook his head.

"Very well, sir," proceeded the tradesman; "when you do, M. C. will be proud to take your orders—ever grateful for past favours, sir, and hoping for a continuance of your kind support. Allow me to give you one of my new cards, sir; you'll see I says as much there." So saying, the pushing little carpenter thrust one of the printed bits of pasteboard into the old gentleman's hand.

Suddenly a loud shout was heard in the street beneath.

Malachy and Mr. Tonkin looked vacantly at one another, as they both inwardly wondered as to the cause of the noise.

In a few minutes the shouting was repeated, and this time the ear, quickened by curiosity, could distinguish the shrill cries of the village boys and women among the rest.

The carpenter, in the excitement of the moment, forgot his customary obsequiousness, and rushing towards the window threw open the little diamond-paned casement, making its metal frame twang again as he did so; and as he craned his neck over into the street he cried, "Oh, Mr. Tonkin, Mr. Tonkin! here, you never saw suchy thing in ale your life!"

The old gentleman was sufficiently curious to be unable to resist sharing in the excitement, and proceeded to join the little carpenter, who was still eagerly surveying the mob that was gathered round about the "Star Inn," on the opposite side of the street.

"It's Squire Giddy's new conveyance, sir!" exclaimed Malachy. "The gardener told me last night it had come down from London the day afore, with all its wheels done up in haybands like an Irish reaper's legs. It's the fust as has ever bin seen in these parts, and so of coose the whole town has come to have a peep at it."

Ay, so it had! All Penzance was out to behold the first carriage that had ever appeared in its streets.

There were the fishwomen from the neighbouring villages of Mousehole and Newlyn, who had stopped in their rounds to join in the throng, and who had their "cowals" or panniers of fish slung round the crown of their broad-brimmed hats, with the load of pilchards glittering like lumps of silver at their backs. And there were the ruddy-faced oil-girls, who had put down their heavy pitchers and ceased for a while their cries of "Buy ma traa-in! Buy ma traa-in!" to eye "the big box upon wheels," as they called it. The portly town-crier, too, was there, with his huge dustman-like bell turned upwards, and looking like a big tulip in his hand; for having found that his audience had suddenly deserted him, and were more attracted by the sight of the new conveyance than with his announcement that the grocer "had just received several chests of the best tea from London," the bellman had himself helped to swell the crowd, and was now as eager as any to obtain a view of the new wonder. Mingling with these might be seen the forms of the boatmen—half-smugglers, half-fishermen—from the neighbouring shore, with their tight-fitting blue "Guernseys," their yellow, greasy-looking, fan-tail hats, and their large high jack-boots, that bagged about their legs and looked as rusty as if they had been made out of brown paper; whilst at the outside of the motley group the eye fell upon the news-boy, mounted on a podgy pony, with his long tin horn in his hand and pad of "SHERBORNE MERCURYS" under his arm; and he, in his eagerness to catch sight of the strange-looking vehicle, was leaning over on one side of the saddle, as a butcher-boy loves to ride. All the shop people were at their doors: some in long aprons, and others with white sleeves on their arms over their coats; and the boys kept darting across from the houses towards the mob; while the upper windows all down the street were knobbed over with heads, each bent towards the one grand focus of attraction.

"It's a queer-looking consarn, aint it, sir?" inquired Malachy; "and there's a good bit a work in it, I've no doubt."

"It's a hideous lumbering affair," responded the old gentleman, as he turned away from the window, "and it's a great pity that persons haven't something better to excite their admiration than the follies of the rich; but there's such a love of luxury coming over our people, that soon we shall become as effeminate as those of the East, who are borne about upon couches when they journey from one place to another. In times past we were a sturdy, energetic race, inured to hardship, and loving, rather than avoiding, exercise; but now we must have soft, easy seats, and beds of down, or we cannot rest. Not many years back the floors of our nobles' houses were strewn with rushes, but at present even our gentry are beginning to find a sanded room unpleasant to their feet, and so they must needs have soft carpets to tread upon—as if they had all at once grown as tender-footed as negroes. There's Squire Austell has already carpetted his best sitting-room; and mark my words! there's sufficient of the monkey in our natures to make his great and little neighbours ape the Squire's manners. Ugh! We shall be as unmanly as fiddlers before many years have passed over our heads. Haven't we got to drink slops for breakfast instead of a horn or two of good strong ale, as they did in our fathers' time? and do you think, sir, strength, and courage, and energy are to be got out of teacups? Soon we shall find it impossible to eat without silver forks, as they do in London already; and, by and by, the dinner-bell will ring at the same hour as the curfew-bell used to toll in olden times —for what's called fashion is setting nearer that way every day. But, thank goodness, we still dine at noon here, and our parties are limited to tea and Pope Joan at three o'clock, instead of grand dinners or dances with Frenchified gavottes, and minuets that begin with the owls and end with the lark. I hate such new-fangled customs! they would put John Bull into stays like a Frenchman, and exchange his top-boots for dancing pumps. Take my word for it, sir, since that four-wheeled aid-to-laziness has appeared in our town we shall shortly find every one of our would-be fine ladies unable to stir a yard from their homes without one."*

"You're quite right, Mr. Tonkin, *quite* right, sir," chimed in the little carpenter; "our rich folk are

* "The state of society in the Mount's Bay only half a century ago," says Dr. John Davy, "was peculiar and different from what it is at present. Cornwall was then without great roads. The roads which traversed the country were bridle-paths rather than carriage roads. Carriages were almost unknown, and carts even very little used. I have heard my mother relate that when she was a girl there was only one cart in the town of Penzance, and if a carriage appeared in the streets it attracted universal attention. Pack-horses were then in general use for conveying merchandise, and the prevailing manner of travelling was on horseback. In the same town, where the population was about 2000 persons, there was only one carpet; the floors of rooms were sprinkled with sea sand, and there was not a silver fork. The only newspaper which then circulated in the West of England was the 'Sherborne Mercury,' and it was carried through the country, not by the post, but by a man on horseback, specially employed in distributing it. . . . . Visiting was then conducted differently from what it is at present. Dinner-parties were almost unknown, excepting at the annual feast time. Christmas, too, was then a season of peculiar indulgence and conviviality, and a round of entertainments were given, consisting of tea and supper. Excepting at these two periods, visiting was almost entirely confined to tea-parties, which assembled at three o'clock and broke up at nine, and the amusement of the evening was commonly some round game at cards, as Pope Joan or Com-

getting more proud and fond of luxuries and vanities every day of their lives. Why, what do you think? they're talking of putting cushions to all the seats of the pews in our chapel, sir, just because the gentlefolks has 'em to their sittings in Madern church! and I give you my word, sir, I've only just finished setting a bright polished steel grate in the withdrawing-room, as they call it, at Castle Horneck. It's just bin had down from London, and I declare one might see to shave one's self in any part of it. It

merce. . . . . Amongst the middle and higher classes there was little taste for literature, still less for science, and their pursuits were rarely of a dignified or intellectual kind. Hunting, shooting, wrestling, cock-fighting, generally ending in drunkenness, were what they most delighted in. Smuggling was carried on to a great extent, and drunkenness and a low scale of morals were naturally associated with it. . . . . . Few places have exhibited greater changes within the last half century than Penzance. Not a single family belonging to the great gentry now in existence west of Hayle, or in the Mount's Bay, was known one hundred years ago."

"Carriages, it may be added, are of French invention. Under Francis I. (A. D. 1515–1547), who was contemporary with our Henry VIII., there were but two in Paris, one of which belonged to the Queen, and the other to Diana, the natural daughter of the French Henry II. There were but three in Paris in 1550; Henry IV. of France (A. D. 1589–1610) had one, but of very rude construction, and without straps or springs. The first courtier who set up this equipage in France was John de Laval de Bois-Dauphin, who could not travel otherwise on account of his enormous bulk. Previously to the use of carriages the kings of France travelled on horseback, the princesses were carried in litters, and ladies rode behind their squires. The first carriage seen in England was in the reign of Mary, about 1553; but the art of making them was unknown in this country at that time. Close carriages never was made to put a fire in, I'm sure. But there's nothing I can do for you in my little way; is there, Mr. Tonkin? I've got the newest designs for furniture just arrived from town by the pack-horse as came in last Monday."

Mr. Tonkin shook his head, and turned towards the window.

"I hope no offence, sir," continued Malachy; "another time, maybe, I shall be honoured with your commands, and then I can only say that your

of good workmanship began to be used by persons of the highest quality at the close of the sixteenth century; Fitz-Allen earl of Arundel is said to have been the first who used them, and this was in 1580; their construction was various. They were first made in England about the year 1590, when they were called 'whirlicotes.' In the year 1601, an Act was passed to prevent the effeminacy of men riding in carriages (43d Elizabeth). The Duke of Buckingham, in 1619, was the first who had a carriage with six horses to it; and the Duke of Northumberland, on obtaining his liberation from the Tower (where he had been imprisoned since the Gunpowder Plot) and hearing that Buckingham was drawn about with six horses to his carriage, ordered, out of rivalry, eight horses to be put to his, and in that manner passed from the Tower through the City."—*Haydn's Dictionary.*

"In the twelfth century carpets were articles of luxury. It is mentioned by old English historians, as an instance of Becket's splendid style of living, that his sumptuous apartments were, every day in winter, strewn with clean straw or hay. This was about the year 1160. The manufacture of woollen carpets was introduced into France from Persia at the end of the sixteenth or beginning of the seventeenth century. Some artisans, who had quitted France in disgust, came over to England and established the carpet manufacture among us about 1750. Our Kidderminster, Axminster, and Wilton manufactures are the growth of the last hundred years."—*Ibid.*

orders shall be punctually attended to by your humble servant, M. C.;" and, having delivered himself of this speech, the pushing little carpenter bowed himself backwards out of the room.

CHAPTER II.

YOUNG HUMPHRY'S RESOLVES.

"The first and last Inn in England, kept by Richard Botheras," was the inscription recorded on both sides of a sign-board that swung backwards and forwards outside a little lonely homestead—more like a cottage than a tavern—standing at the extreme western point of Cornwall.

The open door revealed a room without a visitor; the floor was white with sea-sand, and you could tell at a glance, from the evenness with which the sand was strewn, how scanty were the customers in that part of the world, for it was plain that no foot had trodden it that day. Above the ample chimney-board was ranged a row of bright tin mugs, that had been worn more by polishing than use. The top of the little round deal table that stood in the centre of the room was as clean as if it had been newly planed; and over the painted chest of drawers, in one corner, stood what appeared like a *quire* of tea-boards, which, together with the written paper pasted against the wall, and informing the stranger that "parties were supplied with hot water," gave one a notion of the many visitors who came in summer to take tea at the Land's End.

The host, from lack of custom, was busy in the garden at the back, digging in refuse fish as manure for his next year's crop; and the hostess might be seen in the adjoining out-house, with her arms half buried in a cushion of dough, preparing the week's bread for the humble family.

Suddenly the innkeeper paused, with his foot resting on his spade. His quick ear had caught the clink of a horse's hoofs on the neighbouring granite. The man put his hand across his brows, and looked under it in every direction to see who was coming.

In a minute or two afterwards he ran to his wife, crying, "Come, tidy thaself a bit, dame! Here's Master Davy on his pony Derby jist at hand: he's ale in deep black, too."

The good wife was not long in scraping the dough from her hands, and, having invested herself in a clean apron, was quickly at the door beside her husband, awaiting the arrival of the youthful visitor.

As the innkeeper had stated, the lad was dressed in deep mourning, and the beaver of his hat was completely hidden by the broad crape band that encircled it, while the gloss upon his clothes indi-

HUMPHRY AT THE LAND'S END.—Page 37.

cated the recent loss he had met with. To a casual observer there was but little in the youth's appearance to mark the budding genius which inspired him, excepting the ample forehead and the full black eyes beneath it. He was, however, generally considered an "extraordinary-looking boy." He was of diminutive stature, while the roundness of his shoulders gave him somewhat—as it has been termed — of a "bucolic aspect." His hair was chestnut brown, and hung in neglected curls about his brow; his eyes were dark and piercing, but the rest of his features were anything but finely chiselled. His complexion appeared paler than ordinary, from the contrast of the suit of black in which he was habited, and the dejected air and wet-looking eye gave a melancholy tone to his appearance that immediately enlisted the heart towards the boy.*

* "Davy, it may be remarked, possessed, when a boy, a countenance which, in its natural state, was very far from comely; while his round shoulders, inharmonious voice, and insignificant manner, were calculated to produce anything rather than a favourable impression. In riper years he was what might be called 'good-looking;' although, as a wit of the day observed, his aspect certainly was of the 'bucolic' character."—*Dr. Paris' Life of Sir Humphry Davy*, p. 33. The Doctor afterwards describes young Davy as an "extraordinary-looking boy." "His manners were retreating and modest," says Mr. Poole (one of Davy's oldest friends), in a letter to Dr. Paris, speaking of Sir Humphry in early life; "he was generally thought naturally graceful, and the upper part of his face was beautiful. When he first lectured at the Royal Institution, the

The lad said but a word or two in answer to the greeting of the couple, and jumping from the saddle, gave the reins to the innkeeper, who forthwith led the plump little animal round to the stable.

The instant after the youth had disappeared among the rocks.

"Poor lad! he seems deeply cut up; doan't he, Richard?" said the wife, following her husband to the shed.

ladies said, 'Those eyes were made for something besides poring over crucibles.'"—*Dr. John Davy's Life of his Brother*, vol. i. p. 136. "I was very young," Lady Brownrigg says, in a letter to Dr. Davy, "when I first had the pleasure of seeing your highly-gifted brother. We had been invited by Dr. Richardson to go to his cottage at Portrush, to meet the famous Mr. Davy. We arrived a short time before dinner; in passing through a room we saw a youth, as he appeared," (Davy was twenty-eight years of age at this time) "who had come in from fishing, and who, with a little note-book, was seated in a window-seat, having left a bag, rod, &c. on the ground. He was very intent on this little book, and we passed through unnoticed. When I went into the drawing-room I felt some little awe at this great philosopher, annexing to such a character, at least, the idea of an elderly grave gentleman—not, perhaps, with so large a wig as Dr. Parr, or so sententious a manner as Dr. Johnson—but certainly I never calculated on being introduced to the identical youth, with a little brown head like a boy, that we had seen with his book at the window-seat, and who when I came into the drawing-room was, in the most animated manner, recounting an adventure which had entertained him on the Causeway, and, from his mode of telling it, was causing loud laughing in the whole room."—Given in the *Life of Sir Humphry, by Dr. John Davy*, who speaks of the above account as being "very descriptive of the appearance and manner" of his brother "at this time."

"Ah, that he doa," returned Richard, as he stooped down under the pony to loosen its girths. "He's not tha maze-gerry boy he was a little while agone, when he used to come over here, Greace, with a hammer a cracking all the stones that lay in his way into 'midjons and jouds,' and scrambling, like a young goat, over the rocks after some trumpery bit of stone as took his fancy—just as our Jan do after daws' eggs."

"Yes, that he used to," returned the wife, taking off her clean apron, and carefully folding it up as she talked; "and I've seed Master Humphry come back, after being out all day among the rocks, with his cap full of old stones, as he seemed to prize like as if they was lumps of goold, but such as I wodn't a picked out of 'a stomps' —not I. Ah! there's sad trouble at Varfell now, take my word for it, Richard. Mistress Davy, poor thing! has seen enough sorrow in her time to ha' broke many a stout heart; and here she's left with five young ones, and not a 'cheeld-vean' among 'em as can get a penny to help her. Master Humphry's a good scholard, they say; but larning won't fill the cupboard, Dick; and they tells me, down at Penzance, that Mr. Davy (rest his soul!) was too fond of wasting his money in mines—as we've seen many a family ruined with in our day—to leave his wife anything to fall back upon at this time; though I'm sure I pity the poor widow and her little ones from the bottom of my heart, for it isn't none of their bringings on. Sometimes, do you know, Dick, I fancy as there's a spell on that poor woman."

"Go along with you and your spells!" indignantly shouted the husband, as he held the pail of water for the pony to drink from; "you've always got some stuff of that kind in your head, Greace."

"Well, you may talk as you like, but I shall b'lieve in such things to my dying day," retorted the superstitious little body. "Didn't I go to Madern Well and drop some pins into it; and didn't they fall with their pints together, I should like to know? And wasn't our old sow took ill the very week afterwards, and died on the very day as we'd settled to kill her—eh? Oh! you're as unb'lieving as a Jew; you are, indeed, Dick."

The innkeeper treated his wife's argument with a hearty laugh, whereupon the dame proceeded to cite to him a hundred and one such instances as were current throughout the county, and in the midst of which we must leave the worthy couple for the present.

The restless, pensive boy, had wandered to the extreme point of the land, and here, resting upon a shelf of crag far above the sea, that roared and dashed against the base, he sat for a while, with his tearful eye peering across the Atlantic, vacantly gazing at the huge watery disc that heaved like a giant breast before him. Behind the lad towered tremendous pinnacles of granite, some with their monster blocks ranged in cubes one above the other, like Nature's solid masonry; others with massive stones standing right on end; while some seemed tossed about in such confusion as if the "sixth seal" itself had opened, and the heavens had rained rocks upon the land. Here a large square lump protruded like a bond-stone from the straight sides of some tall pile; there a huge mass was scored through at the top, leaving the blocks standing up on either side of it, as if castellated; and there again was seen a ponderous lump, so delicately balanced on some high peak, that it seemed as if the least gust would topple it over into the sea beneath; while the outline of the whole was as jagged as if it had been gnawed, or as if the entire granite pile were some immense crystal that the sea was gradually dissolving away. Below the height the crags stretched far out into the sea, their black and bluff heads peeping up at different distances through the waves which compassed them with a ring of the whitest foam; while at the end of the winding, broken line, there rose one rock higher than the rest, and on top of this glistened the silver tower of the light-house, that, like a star-tipped wand, pointed the way, as it gave the first glimpse of home to the returning mariner.* Far beyond this, again, the eye could just trace, in the mist of the distance, the cloud-like islands† studding the crystal ring of the horizon, while all the rest was one wide desert of water stretching away to the Western World, that even the fancy was weary-winged in its struggle to reach.

Nor was the scene behind the narrow tongue of land that forms the very end of our island less grand and solemn than that which lay before it. To the southward the pathway was along the edge of a precipice that the sea beneath had scooped into a curve, and here, at one extremity, the ocean had drilled huge caldron-like cavities in the rock,‡ and pouring into these boiled with a roar that made the cliffs boom again with the noise. Beyond this rose the majestic headland of "*Carn-y-Voel*," its summit half veiled by a light scarf of clouds, and its tall sides, built of granite cubes, rising straight as a fortress wall from out the sea. Here the ocean had worked for itself a little bay, where the smooth green water lay like a mirror, with the shadows of the yellowish-red cliffs above it reflected deep into

* These are called the "Long Ships' Rocks," and on one of them is a "light." British ships passing this pay one halfpenny a ton, and foreigners one shilling each vessel; the annual revenue thus obtained amounting to three thousand pounds.

† The Scilly Isles.

‡ Known by the name of "*Enys Dodnan.*"

the pool, and trembling, as the surface rippled, into zig-zag lines that played with a thousand lights and shades. On the other side of this bay a low granite cliff jutted out like a buttress, the green ground above sloping abruptly down; and against this the waves beat and dashed till the spray played around the rocks like a cloud of smoke, and sparkled in the sun delicately tinted with many a prismatic hue. Here, again, the ocean had burrowed into the thick granite wall, while near the verge of the cliff there was a perpendicular shaft, the sides of which were smooth and circular, as if they had been drilled out of the solid rock; and looking down these, as down a dark well, the eye could see the white waves tumbling and tossing below with a terrible fury.*

On the northern side of the promontory, called in Cornish "*Antyer Deweth*," or the Land's End, the headlands were higher than those even on the south, for there one tall rock rose out of the waves towering high into the air, and formed also of granite cubes, which looked in the distance so like a suit of mail, that it had acquired the name of the "*Armed Knight*;" and here at the very top of one of the craggy summits a singular cross of rock was to be seen, while as the eye travelled along the curved and crumpled shore, far away to the north, it rested

* This is called in Cornish "*Tol-Pedn-Penwith*," which signifies the holed headland on the left hand.

on the point of land known by the name of "Cape Cornwall," the outlines and tints of whose slate cliffs, seen through the atmospheric veil, appeared soft and blue with the haze of distance.

Despite the blocks of granite that protruded through the land, like the bones of the earth itself, the ground roundabout was rich in parts with flowers. Now the soil was purple with the richest heaths, and now it was yellow as a plate of gold with the bloom of the dwarf-furze, the latter filling the air with a perfume like apricots, while the green patches of grass were almost iridescent with the various wild flowers that peeped with their delicate blossoms from out the blades. The air, too, was savoury with the odour of the sea, and fresh with the spray that, like a dew, brushed against the cheek. Still amidst the solemn convulsion of rocks and the vast belt of water which encompassed the beholder as far as the sight could stretch, a feeling of overpowering loneliness—a sense of one's own insignificance and helplessness, such as travellers are said to feel in deserts—oppressed the mind there—*there*, at the very brink, as it were, of one's native country—the last bit of the land with which all one's affections and associations were linked—and rapt in a ghastly silence, that was broken only by the moan-like booming of the monster sea, as it beat into the cavities of the cliff far beneath the feet, or, now and then, by the shrill shrieking of the cormorant, or the whirr of some passing sea-mew's wing.*

The boy sat, as we said, for a while staring vacantly at the waves that pranced, like curvetting steeds, before him, and as he did so a heavy tear-drop fell now and then on the moss that spotted the rock at his feet. Sometimes his lips would move, though not a word escaped them, and he would

* Davy is said to have delighted as a boy in visiting the Land's End. In one of his early poems occurs the following passage, in which the spot is spoken of under its Latin name, "*Bolerium:*"

"Thy awful height, Bolerium, is not loved
By busy man; and no one wanders there
Save he who follows Nature—he who seeks
Amidst thy crags and storm-beat rocks to find
The marks of changes, teaching the great laws
That raised the globe from chaos; or he whose soul
Is warm with fire poetic."

"It is surely not difficult," says Dr. Paris, "to understand how it happened that a mind endowed with the genius and sensibility of Davy should have been directed to the study of chemistry and mineralogy, when we consider the nature and scenery of the country in which accident had placed him. . . . . . Nor could he have wandered along the rocky coast, nor have reposed for a moment to contemplate its wild scenery, without being invited to geological inquiry. . . . . . . 'How often, when a boy,' said Davy to me (adds the Doctor), on my showing him a drawing of the wild rock scenery of Botallack Mine, 'have I wandered about those rocks in search of new minerals, and, when fatigued, sat down upon the turf, and exercised my fancy in anticipation of scientific renown.'" (Botallack Mine is situate at St. Just, a town near to Cape Cornwall, and but a short distance from the Land's End.) "The granite and serpentine rocks of his native county were, I believe," says Dr. John Davy, "the first he studied when he commenced the pursuit of geology, and both of them were to him particularly attractive. The finest examples of strike the air with his clenched fist as though a sudden resolution had crossed his mind; then a shudder would pass over his frame, and he would clasp his forehead with both his hands, and sway his body to and fro, as he bent his head almost to his knees. Presently, after a slight pause, he would raise his head, and with his neck stretched back, look steadfastly at the heavens as if gazing at some spirit there. And when this fit was passed, he

these rocks were within a day's ride of Penzance; and when he visited home, a young man, he never failed paying the Lizard and the Land's End a visit, and generally in company with some of his old school-fellows. I remember, when a boy," Dr. D. continues, "being allowed to join one of these parties to the Land's End, and it was a merry one—as youthful parties commonly are. After exploring the cliff scenery, we dined at a tavern at St. Just, and I well recollect the boisterous mirth indulged in when the repast was concluded—the gymnastic feats attempted, the shouts of applause, the unconstrained laughter, and all that abandonment of spirit to mirth so common to young persons under excitement, and which, excepting in youth, can scarcely be felt or enjoyed."—*Life of Sir Humphry Davy.*

In the commencement of a work designed by Sir Humphry Davy upon "The Geology of Cornwall," the philosopher himself gives the following description of the rocks at the Land's End: "In the great arrangement of the masses of granite of Cornwall, the rock appears composed of an immense number of blocks of different sizes. This structure is nowhere more perfectly exhibited than in the western cliffs. The incessant agency of the Atlantic, its storms and its waves, have washed away or destroyed all the loose materials of the shore, and left abrupt eminences of rock from 50 to 360 feet in height. The arrangement of the granite is in masses which approach to the cubical form, having, however, rounded edges, heaped upon each other. . . . The masses are grand, their colours uniform, and their uniformity increases the effect upon the eye; while the arrangements of this kind have would resume his seat, and clasp his hands as in prayer.

Suddenly the boy started to his feet, crying, "Yes, I'll do it—that I will. I will rescue them all — every one — from the poverty that threatens them. I have promised my dead father to do so. I have prayed God to give me the strength and firmness to carry out my purpose, and in a few years our home shall be as happy as it's wretched now.

a peculiar wildness and sublimity. Nowhere is it seen upon a greater scale, or in a more magnificent assemblage of forms, than from a point between the Land's End and Castle Treene. Both these grand promontories appear extending into the Atlantic; the cliffs between them are abrupt and lofty; the waves are broken by a number of small island rocks, which are scattered along the shore. The few portions of soil that appear above the cliff are covered with short green grass, tufted with heath and furze, which, in the autumn, present mixed hues of purple and gold. The rock throughout is of a uniform yellowish red, the tint perfectly contrasted to the blue-greens of the sea." (Castle Treene, or "Castle Treryn," as it is more correctly written, is a headland beyond "St. Levan churchtown," as it is sometimes called—though the chapel which formerly stood there has been many years since washed away by the sea, the steps alone now remaining.) St. Levan lies a little to the eastward of the headland called "*Tol Pedn Penwith.*" A short distance from St. Levan is "Port Carnow Cove," which is bounded on the eastern side by rocks that jut far into the waves, and rise to a great height, being heaped one on another, in magnificent order. Here stands the noble headland called "Castle Treryn," above whose summit two huge slanting and imposing masses of granite protrude. There is a fissure between these masses leading to a smaller group of granite rocks, on the top of which the huge Logan stone (weighing some 65 tons) stands so delicately poised, that by clambering to a fearful height at one of the angles, it may be made to sway to and fro with the least force.

I feel as if I had just woke from a long dream. What a thoughtless, idle fool, I've been! but it's past—never to return. Poor mother! I've cost her many a tear, I know, of late. How have I wasted this last year, when I should have been at some business seeking the means of adding to my mother's comforts, instead of lessening the little that is left her at such a time as this! If I had only worked instead of squandering my time in silly pleasures, I might now have been a help to her rather than the wretched burden I am—without the power to earn a crust for myself. What do I know that is of use to any one? Who would give me a penny for anything that I can do? and yet I'm old and strong enough to get my own living. Oh, shame! shame! that I, at my time of life, should have to take from poor mother's little store. If I'd had a proper spirit, I should have felt this long ago: but no matter, it's ended now; and I'll go to work and so fill my mind with knowledge that mother shall soon be as pleased about me, as I know, poor thing! she has been pained of late. Yes, and father will watch over me; I know he will. Oh! if I could only have changed before he died, what a comfort it would have been to him in his last moments: but as it was, I, like a wretch, let him leave me in doubt as to what was to become of me. Why didn't I wake up before? If it had only been a month ago, he might have felt no pain on my account. Oh, shame! shame! but, thank

God, I'm different now, and I'll go back home and tell mother all I mean to do. I've the power in me —I know I have. I'll go back and tell her not to grieve, and that I'll do all I can to help her and my brother and sisters for the future."*

* Dr. John Davy says, "The greater part of the year following" (the period of his quitting Dr. Cardew's school at Truro, which Humphry did at the age of fifteen, when his school education was considered as complete) "he was, I believe, in an unsettled state, studying in a desultory manner, by fits and starts, and yielding to the allurements of occasional dissipation, and the amusements which constitute the delight of active youth —as fishing, shooting, swimming, and solitary rambles. *This was perhaps the most dangerous period of his life, and in conversation with me he has so spoken of it.* Amusement threatened for a time to obtain the mastery, and keep him down to the common level; but his good genius triumphed, and, after a few months' vacillation, he applied himself in earnest to the cultivation of his mind and to the acquisition of knowledge; and the flame once kindled burnt on till it expired in death." Speaking of the circumstances which induced Humphry to relinquish all his boyish habits about the period of his father's death, his brother says: "*This event, probably, had a powerful effect in giving steadfastness to his resolution, and I am quite certain that the circumstances of his family became with him an additional and powerful motive to exertion.*"

"Like most young persons, Humphry when a boy," says Dr. John Davy, "was fond of declaiming, and indulged in it in his solitary walks and rambles. On one occasion it is recorded of him, that, on his way to visit a poor patient in the country" (during his apprenticeship), "in the fervour of declamation, he threw out of his hand a phial of medicine which he had to administer, and that when he arrived at the bed-side of the poor woman he was surprised at the loss of it. The potion was found the next day in a hay-field adjoining the path" (p. 55).

CHAPTER III.

HUMPHRY AND HIS MOTHER.

The resolution once formed, young Humphry hastened to convey the glad tidings to his mother, and as he rode along he kept talking to himself all the way, running over the many "fine things" he meant to do for the future, and dreaming that some day he might perhaps become distinguished for his learning and wisdom. He amused himself, too, by speculating as to what he would do with his money if he ever got to be rich. He would have his little brother John well educated then, and comfortably started in life. Yes! and he would give up his share in the property at Varfell to his mother and sisters—*that* he would do first of all; and if he grew to be a very wealthy man, he would give a certain sum of money to the Grammar-school, so that the boys might have a holiday every year on his birthday—he would like to be able to do *that*, for then he would be remembered by them as long as the school lasted. Further, he would give something a year to his aunt Sampson's Phillis, and his aunt Millett's maid as well. Poor Mary Launder and Betty

White should get something, too; and he would have a number of old pensioners besides, that had known him when he was young. He would take care, moreover, that his pony Derby and his dog Chloe wanted for nothing in their old age, and wherever he might be he would have a box of apples sent him at Christmas from the tree he had planted in the garden when he was a little fellow.*

On reaching the humble farm at Varfell, Hum-

* The greater number of these resolves were fulfilled in after-life. Dr. John Davy says: "The interest he took in me more resembled that of a father than a brother, and it is with peculiar pleasure I reflect on his various kindnesses—my numerous obligations, many of which were delicately concealed at the time—his valuable hints and generous regard to my studies, leaving me free to follow the bias of my own mind—and his excellent advice in respect to my conduct, in which was always infused a native nobleness of sentiment well adapted to stir up virtue in a young mind." In one of his letters to his brother, Sir Humphry says, "You must study your own plans with respect to study. Pray do not care about the expense, if it adds anything to the comfort or respectability of your situation. I will, if you like, send £40 a year, in addition to what my mother sends you. My dear John, let no difficulties alarm you; you may be what you please. Let no example induce you to violate decorum—no ridicule prevent you from guarding against sensuality or vice. Live in such a way that you can always say the whole world may know what I am doing."

Dr. Paris says: "No sooner had Davy found himself in a situation which secured for him the necessaries of life, *than he renounced all claims upon his paternal property in favour of his mother and sisters*." In a letter to one of his sisters, Davy says: "I enclose a one-pound note, which you will lay out in books or in anything else you like. I enclose another one-pound note, which I wish to have disposed of in the following manner: To Mary phry found his mother seated beside a table, the top of which was black with a hillock of little skirts and bodies that she had been busy making up for the children's week-day wear. The quick eye of the boy could distinguish as he glanced at the pile of mourning that the gloss of the bombazeen was dulled in places with the tears that had fallen upon it.

Humphry, from a sense of the grief that pervaded the house, had entered the room so softly that

Launder, 5*s.*; to Betty White, 5*s.*; and with the rest you will buy some ribbons or little articles of dress for the Doctor's Jenny, my aunt Sampson's Phillis, my aunt Millett's maid, and my mother's servant, as New-years's gifts." In another letter he writes thus: "I enclose a ten-pound note, which I beg you will lay out in the way you think best for my sister's children and any *old pensioners* that knew me in my youth." "No Swiss peasant," says Dr. Paris, "ever sighed more deeply for his native mountains than did Davy for the scenes of his early years. He entreated his nurse (when ill at the Royal Institution) to convey to his friends his ardent wish to obtain some apples from a particular tree which he had planted when a boy, and he remained in a state of restlessness and impatience until their arrival." Moreover, it should be stated, that, in addition to his will, he left at his death a paper of directions, which have been religiously observed by his widow. In these he desires that the interest arising from £100 stock may be annually paid to the master of the Penzance Grammar-school, on *condition that the boys may have a holiday on his birthday.* "There is something," adds Dr. Paris, "singularly interesting in this favourable recollection of his native town and of the associations of his early youth. It adds one more example to show, that, whatever may have been our destinies, and however fortune may have changed our condition, where the heart remains uncorrupted we shall, as the world closes upon us, fix our imaginations upon the simplicities of our youth, and be cheered and warmed by the remembrance of early pleasures."

his presence was unperceived by the widow, and for a minute or two he stood watching his mother as she sat there with her flooded eyes fixed intently on the large carved oak-chair (her late husband's handiwork) that stood beside the mantel-piece. Her cheek rested on her hand, and it was plain by the fixedness of her gaze that the seat was no longer empty to her, and that her mind was far away in the past.

The sight of that sad wife, widowed almost in her youth, was sufficient to have touched many a stouter heart than young Humphry's. The widow's hair was still unsilvered by age, and its blackness contrasted forcibly, and even painfully, with the close white muslin cap that half concealed it. The dead black of the crape made her cheek as pale as marble, while the tears that dewed her eyes gave them an almost glassy look, so that they seemed jettier than usual. Her face, though young in years, was prematurely old in expression, for the features, which were naturally well formed, were pinched; and there was an air of mild resignation over the countenance that told you the poor woman had long ago learnt to bear affliction, almost without complaint. Nor did it need a second glance to discern the tenderness and affection of her nature*—for though there

* "In all the various situations of life in which my mother was placed," says Dr. John Davy, "she so conducted herself as to gain the regard and good-will of every one. She possessed a most kind and affectionate heart, a pious mind, sound understanding, and perfect integrity. She was devoted to the per-

was a settled melancholy in her face, there was still so much kindliness in its expression that the heart could not help extending to her the sympathy that it knew she would be the first to afford to others who had seen as much trouble as she herself had in the course of the few years that had passed over her head.

Humphry drew towards his mother's chair, and resting against the back curled his arm gently about her neck. So unexpected, however, was the embrace, that the widow shrieked with alarm as she was suddenly roused from her melancholy reverie.

The next moment, pleased at the idleness of her fright, she clasped the pet boy to her; and while the tears gushed from her eyes she kissed him again and again, as though she loved him the more now that he and her other children were all that she had left to engross her affection.

"What! in tears again, mother?" said Humphry, in a tone of kindly remonstrance. "Nay, do

formance of all her duties, and was remarkably free from all guile and foolish pride. When she became a widow, she was in her thirty-fourth year, with five children, all of whom were still to be educated, excepting Humphry, her eldest son. Her income at this time was about £150 a-year, and it was encumbered with a debt of about £1300, contracted by my father chiefly in consequence of losing speculations in mining. Her good resolutions did not fail her on this trying occasion; she met all her difficulties with courage and prudence."

Dr. Paris, speaking of Davy's mother, says: "She was remarkable for the placidity of her temper and for the amiable and benevolent tendency of her disposition."

not grieve," he added, as the widow rested her head on his bosom, "I have come to promise you that I will do all in my power for my brother and sisters."*

"But what can *you* do, Humphry, my good lad?" asked the mother, as she looked up through her tears and smiled at the youth. "It will take you some years before you can earn a livelihood, and even then perhaps you will gain only sufficient for your own wants. What is to become of my little ones is more than I can bear to think of. How you, too, Humphry, are to be put out in the world, I'm sure I cannot say. My means, when all the debts are paid, will be only £100 a-year, if that."

"There, there; have no trouble on my account, mother," returned the lad. "I've made up my mind to lay aside all my idle habits, and to set hard to work at something directly—though I cannot tell what, just now; and you shall see I won't be long before I make you all happy here."

The mother half laughed at the sanguineness of her son, and said, when she had kissed him for his kindness, "But you talk like a boy, Humphry. You don't know how hard it is to earn money yet."

"Yes I *do*, mother," replied the determined youth,

* "My brother," says Dr. John Davy, "at the time of my father's death was sixteen years old. Seeing her (Mrs. Davy) in great affliction, he, in a very affectionate manner, begged her 'not to grieve,' saying that '*he would do all he could for his brother and sisters.*'"

as he pressed her hand. "But I feel I have the power in me, and I'll *do* it, you shall see—all by myself too—aye, *that* I will, if I have to study night and day. You don't know what a lesson poor father's death has been to me. I never saw you in grief before, and all this last week my mind has been at work, for your tears were more than I could bear. Not a night of late has past but I have reproached myself over and over again that I had wasted the last year of my life, instead of doing something that would have given me the power to help you at such a time as this. When I heard Mr. Tonkin, too, talking with you the other day about the money you would have to live upon, and heard him say that it was high time I should cease being a burden to you—yes, those were his words, mother—a *burden*" (and the boy would have turned away from the widow, but she held his hand), "I felt the blood rush into my face with shame, and a new spirit came over me. I didn't say anything to you, mother, at the time, because I thought I could hardly trust myself; but I went on thinking I *was* a burden to you, and the heaviest burden of all, too. So I kept brooding and brooding it over, until at last I made a solemn determination that, instead of a burden, I would be a *help* to you and my brother and sisters for the future. I have sworn it, mother! I have promised my poor father to do so this very day—alone among the rocks I made the vow, and I'm sure he heard me, for I feel as I never felt before, and I *know* I've the power to do as I have said."

The mother in her delight hugged the boy passionately to her bosom, and as her tears fell thick and hot upon him she said through her sobs, "You *have* the power, I know, Humphry; and if this sad bereavement which has come upon us all does but stir you to make use of the genius that is in you, it will be indeed almost a recompense for the heavy loss we have sustained. When you were but a child, I used to tell your dear father of the bright hopes I had of you, Humphry, and that I was sure you would be very clever some day; though he, poor man! only smiled at my words, and thought it was my over-fondness that made me fancy as much, saying all mothers did the same. But *I* knew differently, Humphry; I could see you were not like other children, and even from an infant there was hardly anything babyish about you. When you were only five years old you made rhymes of your own, and used to recite them in the Christmas gambols, and I knew there was no little thing of that age that could do the same thing in these parts."

"Yes, I've often heard you say so, mother," added the boy, smiling at the youthful reminiscence.

"You were a very forward child—from a baby I may say, Humphry," continued the proud mother, as she passed her fingers through the lad's hair, and brushed it from his forehead—for she half forgot her sorrow as the recollection of her pet boy's feats stole, one after another, across her mind. "Why, you were only nine months old when you walked off, all by yourself; and you could speak as well, and fluently, as a little man, before you were two years of age. Shall I tell you, too, what you said when your sister Kitty was born? little sharp thing as you were! The servant had been assuring you day after day, that when the baby came you'd be no longer petted in the way you had been—for then, as the maid said, 'your nose would be put out of joint.' This seemed to make a great impression upon you, for directly you saw little Kitty you put your chubby fat hand up to your face, and cried, 'Mamma! my nose not out of joint at all.'"

"Did I?" laughed Humphry.

"Yes, that you did," said the mother. "Ay, and before you had learned to write you used to copy the figures in 'Æsop's Fables,' and print the names of them in big letters underneath. I really think, too, you couldn't have been more than four years old when you could recite a good part of 'Pilgrim's Progress.' All I know is, you did so before you could read well the book; for your memory was so great, that anything you had heard once or twice you could repeat, almost without a mistake, afterwards; and when you were sent to

Mr. Bushell's school—you remember old Mr. Bushell, Humphry—you made such rapid progress there in your reading and writing, that though you were only six years of age, the old gentleman, against his own interest, recommended your poor father to remove you to the Grammar-school.*

* "It is remembered," says Dr. John Davy, speaking of Sir Humphry's infancy, "that he walked off (to use a nursery phrase) when he was just nine months old; and I have been told, that before he was two years of age he could speak fluently. About this time my eldest sister was born, and he was told by a servant, that on her appearance 'his nose would be put out of joint.' On seeing the baby, it is related of him, that he put his hand to his nose, and said, 'Mamma, my nose not out of joint.' Before he had learned to write, he amused himself with copying the figures in 'Æsop's Fables,' and under his drawings, in great letters, he contrived to give them their names. His memory was very retentive, in proof of which it is handed down in the family, that when very young he could recite a great part of 'Pilgrim's Progress,' even before he could well read it. I believe that, like Pope, he lisped in numbers. I remember hearing my mother say, that when scarcely five years old he made rhymes, and recited them in the Christmas gambols. His disposition as a child was remarkably sweet and affectionate. . . . . The first school he was sent to was that of a Mr. Bushell, at which reading and writing only were taught. This master, then an old man, remarking the rapid progress of his young pupil (he was then six years old), in a very disinterested manner recommended my father to remove him to the Grammar-school."

"It is a fact," says Dr. Paris, "worthy, perhaps, of being recorded, that Humphry Davy would, at the age of five years, turn over the pages of a book as rapidly as if he were merely engaged in counting the leaves or in hunting after pictures, and yet, on being questioned, he could generally give a very satisfactory account of the contents. The same faculty was retained by him through life."

"When you could read, too, I often watched you at your books, and saw you turn over the pages so fast, that I fancied you were merely counting them, or hunting for pictures; but on talking to you about the book I used to find, to my astonishment, that you had read it through in that short time, and that you really knew all about it, and could give a much better account of it than children who might have taken hours, or perhaps days, to get through it."

Humphry drew closer to his mother, and pressed her hand between his palms as he looked up in her face, and smiled with delight to hear her run over all the feats of his youthful genius; for with the history of each little wonder he felt the faith he wished to have in his own powers grow stronger in him, and he shook his head proudly as he inwardly thought of the greater wonders he would achieve in the time to come.

"Go on, mother," he said, as he seated himself on the stool at the widow's feet, "tell me some more things I used to do when I was a little fellow—tell me some more, they fill me with the same hope as you say they did you, and I want to have all the trust I can in myself; for I've made up my mind to be a great man, and if I doubt my power to accomplish the task I have set myself, I shall, perhaps, give it up almost at the first difficulty. Tell me something more, mother; I want all the faith in myself you can give."

"I wish I could give you as much confidence in your own powers, Humphry, as I have in them," returned the widow, "though now you begin to speak with all the aspirations I have longed to see coming upon you; and for the last year I cannot tell you how grieved I have been to behold one, of whom I had formed such high hopes, giving himself up to pleasures that serve to breed only habits of thoughtless amusement rather than wise reflection."

"I know I have pained you, mother," added Humphry, "but it's all at an end now. You remember when I was at the Grammar-school, how Mr. Coryton used to pull my ears for not minding the lessons he set me. But do you know, mother, I have often thought, that though I learnt little at Mr. Coryton's school, it was, perhaps, better after all that I should have been left to teach myself; for what we learn from our own liking, we seldom forget; and I am sure I remember more about the books I have had from Mr. Tonkin, and that I used to read through one after the other as fast as I could get them, than all the Latin and Greek I was forced to get by heart at school."*

* "The Rev. Mr. Coryton (the master of the Grammar-school) was a man of irregular habits, and ill-fitted for the office of teaching youth. He was occasionally severe, and punished heavily slight offences. Pulling the boys' ears was practised by him in the most capricious manner, and my brother was too frequently a sufferer from this infliction. It is recorded of Humphry Davy,

"Ah, but Mr. Coryton," interrupted the mother, "was a man little fitted for teaching youth, Humphry. He was careless about the boys' studies, and often very severe for the slightest faults. I remember once you went to school, unknown to me, with a large plaster on each ear, and when Mr. Coryton asked you 'what was the matter with your ears,' you told him 'that you had put the plasters on to prevent a mortification.' But if you didn't stand very well with the master, you were at least in high favour with the boys, Humphry, for you used to do the Latin and English verses for half the school; and as for writing valentines and love-verses, why I am sure your play-time was mostly taken up with

that he appeared before Mr. Coryton with a large plaster on each ear, and that when asked by his master 'what was the matter with his ears,' he replied with a very grave face, 'that he had put the plasters on to prevent a mortification.'"—*Dr. John Davy*, p. 14. In a letter to his mother, Sir Humphry Davy says, speaking of this school, "I consider it fortunate that I was left much to myself as a child, and put upon no particular plan of study, and that I enjoyed much idleness at Mr. Coryton's school. I perhaps owe to these circumstances the little talents that I have, and their peculiar application. What I am, I have made myself. I say this without vanity, and in pure simplicity of heart." Davy seems, indeed, to have been more distinguished out of school, and by his comrades, than by any great advance in learning. "From his facility in composing Latin and English verse," says his brother, "his assistance in these exercises was often requested, even by boys much older than himself; and in writing valentines and love-letters, he shone so pre-eminently, and gave his aid so willingly, that he is said to have been generally resorted to on all emergencies of boyish loves. Another cause of popularity among his comrades was his power of diverting them by scribbling rhymes to first Miss This and then Miss That for some little urchin in a jacket, who fancied himself to be smitten with the young lady. Then of an evening you were always to be found under the balcony of the Star Inn—for you were sheltered there—with a group of boys round about you; and, if there happened to be a cart on the spot, you would be sure to mount it, and there you'd remain narrating all kinds of romantic stories to the little mob of school-fellows who came regularly to listen to you. I never knew such a boy for story-telling as you were, Humphry! I have many a time heard you make up the strangest kind of tales out of your own head; and while I was in the parlour at work,

telling them stories; and so attractive were the tales, commonly of wonder and terror, which he related, that they were in the habit in an evening of collecting at a particular place to wait for him, as under the balcony of the Star Inn, which afforded shelter, and where, if there happened to be a cart, he would get into it, and hold forth to his young audience." (*Idem*, p. 15.) "The earliest indication that I am aware of," says Davy's brother, "which he showed of his fondness for experimenting, was in making fire-works. My eldest sister well remembers that she was his assistant in this undertaking, and that their workshop was an unfurnished room, in which, in bad weather, the Rev. Dr. Tonkin (the elder brother of Mr. John Tonkin, the friend of our family), then advanced in age and a valetudinarian, took exercise on his chamber-horse—a large arm-chair attached to spring-boards, which boards served for a table for compounding the ingredients of the squibs and crackers." "Davy," says Dr. Paris, speaking of his youthful amusements, "was in the habit of preparing a detonating composition, to which he gave the name of 'thunder powder,' and which he would explode on a stone, to the great delight of his young playfellows" (p. 5).

I used to listen to you, as you and young Batten sat out in the porch, with your arms curled round each other's necks, and you would be there hour after hour; for you were never tired of inventing, nor he tired of listening to the stories of wonder and terror you both delighted in."

"I can remember it all well, mother," added Humphry. "And do you recollect how fond I was of making fire-works, and how Kitty used to help me till her fingers were as black as sticks of liquorice with the gunpowder; and how we used to mix up the composition for our squibs and crackers on the spring-boards of old Dr. Tonkin's chamber-horse that stood in the empty room, when we lived at Penzance, and that the poor old gentleman used to take his exercise upon in wet weather?"

"Yes, *that* I do, Humphry," smiled Mrs. Davy; "and many a time you have nearly frightened me out of my wits with your 'thunder-powder,' as you called it, which you used to delight in putting under the chairs, so that the moment any one sat down, there was such an explosion that everybody in the room felt as though all their bones had been suddenly broken. Your poor father only perceived in such tricks an idle, thoughtless disposition; but women see more keenly into character than men, and I not only recollected, but knew, the quick boy you were, and how rapidly you could acquire anything to which you applied yourself;

besides, I had noticed your inventive turn from a child, and the force of your imagination in the stories you made up and the poems you had written—for at twelve you had composed an epic that I have by me still—and all these things gave me assurances that one day you would take a foremost place among the great men of the country. A mother's heart may have led me to have these hopes of you, Humphry; my understanding, however, convinced me that they were not mere dreams begotten by affection, but conclusions calmly come to after narrowly watching—as a mother only can watch—every little turn and trait in your character."

"No, mother!" burst out the boy; "they are *not* dreams, but clear foreseeings; and you yourself shall witness the realisation of them before many years have passed."

"God grant that I may live to do so, my boy," murmured the widow, as she raised her eyes to heaven. "'Life,' as some wise man says, 'has few better things to give than a talented son,' and it seems to me there can be no greater pleasure to a mother's heart than to witness the genius which she has watched bud and expand from year to year ripen into excellent wisdom, and come to be acknowledged and reverenced by the world at large—no joy more exquisite to a woman's nature than that which she must surely experience on finding that the mind which she had tended from its very dawn—catching up the first glimpses of intellect, and garnering them in her bosom as household wonders and bright things of promise—has fulfilled all her best hopes, and that the visions she had formed of the fame and honour that were to attend her boy in after-life have not been mere dreams of her admiration or her pride. But rather, that the being whom she has loved, and wished to have loved by others, lives to be at length praised and esteemed by all, for the talents and virtues that she was the first to notice and to foster. This, Humphry, is the brightest and sweetest reward a woman can meet with in her old age; and, having reaped it, she parts from life with a sense of duty fulfilled, and a feeling that the affection with which she welcomed her child into existence, and the care with which she tended him in his youth, have not been unprofitably bestowed, but repaid her in the richest coin the world can offer to a parent."

Humphry for a while remained in silence, while his mother's words sank deep into his soul; then he said, softly, "May it be my proud lot, mother, to render you such a reward. I am thankful to the Creator that I have passed through the most dangerous portion of my life with few errors, and I hope to devote myself for the future to pursuits useful to mankind, and which in after years may perhaps obtain for me the applause of enlightened men."*

The widow laid her hand on the boy's head as he sat at her feet, and she said, solemnly, "My blessing be on you, my son. May God give you strength to maintain your noble purpose!"

Then she threw her arms about him, and bursting into a flood of tears, cried, "Oh, my boy! my boy! you know not how happy you have made me. Your words are like oil to my wounded heart. Sometimes, of late, I have wondered why it should please Providence to visit me so sorely—*me*, who never knowingly injured any one in thought or act. And yet, even almost in my infancy, I was deprived of father and mother at one blow, so that the very features of my parents are unremembered by me, and the blessing of their love a joy I was scarcely allowed to taste. And now, before my own children are able to help themselves, he who would have been their best protector is snatched from me, and I again am alone in life, bereft of the love and care I had hoped

* The above are Davy's own words, taken from a fragment of a letter which his brother says exists in one of Sir Humphry's note-books, kept during his youth, and which was addressed to one of his early home friends, the letter itself being descriptive of his escape from the vices which are the most seductive to youth in towns. "An active mind," he writes, "a deep ideal feeling of good, *a look towards future greatness*, has preserved me from these."

to share for years to come, and left with five young children, and only a woman's arm to shield them from the buffetings of the world. It needs no little faith in the goodness of God, Humphry, to believe that there is a *mercy* in all this; and often, in the bitterness of my tribulation, I have been wicked enough to doubt it: for I, with my mind distempered by suffering, could discover no trace of kindness in it all. But *now* I see the purpose of my affliction. It was to stir you, Humphry, to be a protector to your brother and sisters—to develop the high and noble nature with which you had been gifted, and to raise up to me a son, the glory of whose future renown should be something like a recompense to me for the partner I have lost—a son who should be the means of contributing not only to the comfort and happiness of my children, but to the welfare of mankind at large. Yes! I understand the reason of my trials now: and look you, my dear boy, how good comes of evil. The first privation I and your aunts suffered was the means of creating for us such a friend as is seldom met with in this world; I mean Mr. Tonkin, who was not only a father to me and my sisters, but has extended his goodness to our children—for you, Humphry, have passed more of your time with him than under your poor father's roof. And now, no sooner is my husband taken from me than *you*—the giddy boy, who had of late been so absorbed in pleasure that I had almost begun to think the hopes I had formed were nothing but a mother's vanity—become quickened in an instant with a new nature, as if suddenly exalted into manhood, instinct with generous purposes and noble determinations; and, though you are but a mere youth in years, ready to supply the place of a father to your brother and sisters, and a friend and protector to me."

CHAPTER IV.

THE FIRST DRINK AT THE WELL.

A few months had wrought a great change in the household at Varfell.

The widow, when the stupor of her grief had passed away, and the mental absorption of her first sorrow had given place to the calm reflection of melancholy, soon began to see that the comforts and education of her children demanded energy rather than tears from her.

Then came the struggle. What could *she* do to help them? And what would the people think and say if this or that were done?

But Mrs. Davy was not the woman to be daunted by the petty exultation of neighbours; so that when an opportunity offered for her to embark in business as a milliner in the neighbouring town, it cost her hardly a pang—free as she was from all silly pride—to sink from the worldly rank of the gentlewoman into the humbler station of the trader.

Accordingly, after consulting with Mr. Tonkin upon the matter, she was duly installed, in conjunction with a young French lady, as dressmaker and milliner, in a little shop in the town of Penzance.

Nor was Humphry long in finding a fitting occupation. Mr. Tonkin, to whom the youth had communicated all his determinations, and who loved the youth almost as if he had been a child of his own (for the greater part of Humphry's life had been passed with the old gentleman), was as pleased as the widow had been to hear of the new spirit that had come upon the lad; and although the boy's foster-father was not so sanguine as his mother had been of the world-wide renown that awaited Humphry in after life, he had, nevertheless, sufficient faith in the talents of the youth to believe that he might, by application, ultimately win his way to competence and respect among the circle of his native town. Accordingly, when the ardent boy spoke to the calm old man of the fame and honours he had made up his mind to gain throughout Europe—saying, with all the fervour of a boy-poet's nature, that he was resolved his mind should become a light to all nations, and that his name should be linked with noble associations in every enlightened country, Mr. Tonkin smiled incredulously (but still with good humour) at the ambitious dreams of the lad, and told him he was afraid one so young as he knew not how difficult it was to excel, even in the most trivial thing, when we had the entire world for rivals; and that powers which appeared great in the narrow circle of our own family, grew less and less as the arena of competition was widened. Therefore, if the youth, instead of regarding the whole of Christendom as the theatre in which his future powers were to be displayed, would but limit his views to the humble town of Penzance, Mr. Tonkin said he thought Humphry might, with industry and prudence, some day attain a reputable position in the neighbourhood;* adding, that he should consider himself well rewarded for the care and

* When Davy was offered the appointment of Superintendant of the Pneumatic Institution at Bristol, "he accepted it," says his brother, "with the consent of all his friends, excepting Mr. John Tonkin, who had hoped he would have settled at Penzance; and who," Dr. Davy tells us in another place, "was so angry with Humphry for accepting the appointment, that he made some alteration in his will in consequence." Dr. Paris's version of the affair is as follows: "His old and valued friend, Mr. Tonkin, not only expressed his disapprobation of the scheme, but was so vexed and irritated at having *his favourite plan of fixing Davy in his native town as a surgeon* thus thwarted, that he actually altered his will, and revoked the legacy of his house, which he had previously bequeathed him. Mr. Tonkin died on the 24th December, 1801; so that, although he lived long enough to witness Davy's appointment to the Royal Institution, *he could never have anticipated the elevation to which his genius and talents ultimately raised him.*"—*Life of Sir Humphry Davy*, p. 39.

affection he had bestowed upon Humphry if he should live to see him settled as a surgeon in his native town.

It was a lovely autumn evening—such an evening as, at the decline of the year, is known only in those parts of our island which, from the mildness of their climate, have been styled "the Florence of the North." Mr. Tonkin and Humphry had strolled out by Marazion towards St. Michael's Mount, journeying along the curved shore of the magnificent bay, with the ocean spread out on one side, in a broad expanse of unsullied azure, and fringed with a thin border of silver foam, as the waves came rippling lazily over the yellow sands. As they sauntered along, the breeze at sundown began to set from the land towards the ocean, and, sweeping across the warm earth, it came laden with the perfumes of the many exotics that bloom in the open air in that part of the world—the garden of England; for it was just the hour when the flowers love to pour their odours into the lightened air, like incense from a thousand chalices. The rays of the declining sun gave a faint tint of purple to the atmosphere, and the green sward, that was still lustrous with the slanting light, was striped, here and there, with the long shadows that streamed from every object intercepting the beams; while the outlines of each form were growing more and more definite, and the sides and peaks of the rocks glittered towards the west, as if they were blazoned with red gold. The brown cattle were quiet in the fields, and the tranquil flocks on the distant hillsides rested there like clouds; the branches of the trees beside the roadway were shaggy, almost to the tops, with the long stalks of wheat that dangled from the twigs, telling of some high-laden harvest-waggon that had lately swept by them. The white-bellied swallows skimmed low over the earth in zigzag lines, twittering as they went; and there was a soothing stillness all around that bathed the soul in balmy quietude.

Towards the sea the scene was no less beautiful. The ocean was like a huge green gem, and here and there on its surface tiny boats seemed to revel in the sundown breeze, now that it had sprung up, and leant over on one side, as they went ploughing through the liquid field, turning up the white surf on their way, and leaving far behind them a long trail, that looked in the distance like a seam upon the water; while in the offing tall ships stood against the sky, with their sails pouting and shining white in the sun, like a pigeon's breast. Nearer the shore rose the majestic rocky mount of St. Michael, towering above the sea like one of Nature's pyramids, with the broken outline of its ivied sides showing sharp and clear against the grey, ariel distance; one half of it, towards the east, was dusked in deep rich shadow, while the other, towards the west, was bathed in such a glory of ruby light, that the Mount shone as if it had been one huge carbuncle studding the bright shield of the ocean. Then, in the far west, the sky and the sea were as a sheet of molten gold; and, almost resting on the ring of the horizon, was seen the round, liquid orb of the sun, trembling like a well of light, with the broad beams streaming upwards from it, and tinting the distant masses of cloud, now ruby and now purple, till they looked like islands of garnet and amethyst in the heavens.

It was low water, and the couple crossed by the sands from Marazion to the Mount; and here, after passing the little cluster of fishermen's houses that skirted the base of the rocky pyramid, and mounting a short distance up the cliff, they sat for a while enjoying and discoursing of the many beauties of the majestic scene that encompassed them on every side.

And the prospect thence was indeed of the grandest character. The shore stretched away, revealing headland after headland, to where the Lizard shot out far into the wave, the rocks there seeming almost phosphorescent in the sun. Then appeared St. Clement's Island and the coast towards the Land's End, forming a shorter cape, and completing the horn of the crescent of land towards the west, that looked, as the waves grew crimson in the sunset, as if bathed in a sea of wine. The ocean here wore its most imposing attribute of uncontrollable immensity; for the Atlantic, across the Bay of Biscay to the most western land of Spain, lay on the south, and melted into distance there; while, beyond the extremity of our own island, no shore intervened on the north between the line of the horizon and the land of the New World.

It was a sight that Humphry loved as deeply as old Mr. Tonkin to look upon, and the couple sat for some time silently watching both the seas rolling there towards the far distant Spanish and American shores.

The boy, however, less capable of continuous attention to the same subject, got to weary of the scene sooner than the old man; and when Mr. Tonkin noticed Humphry's admiration begin to flag, he availed himself of the quietude of the time and place to incite a taste in the lad for the profession he wished him to follow.

Presently the old doctor caught sight of one of the little transparent zoophytes that had been left on the rocks by the receding tide. In size it was not larger than a bird's egg, of a globular form, with several transparent ridges ranged along it, from pole to pole, as it were, and it was nearly as pellucid as the purest rock-crystal.

"Look, my boy," said Mr. Tonkin, turning to Humphry, and pointing to the little ball of jelly at

THE FIRST DRINK AT THE WELL.—Page 76.

his feet; "here is an orb almost as wonderful as the sun we have been lately gazing at. It gives light, too, like it; and though it looks there as if it were only a few drops of the ocean gelatinised, it is quickened with life, and performs motions that our wisest engineers can but clumsily imitate."

The eager boy was about to seize the wonder, so that he might examine it more minutely.

"Nay, if you touch it," cried the old man, hastily, as he grasped the youth's arm, and held him back, "it will immediately dissolve—thaw, as it were, to death—so frail is its life, and nothing but a little pool of water will remain of a creature that once could make the sea glow with its fire. These little things are by some styled the 'lucid gems of the waters.' By daylight, when in the ocean, they are visible only by the bright rainbow hues that mark their path as they paddle along; but by night, Humphry, they blaze with phosphorescent fire, so that some have termed them 'the stars of the sea.' In warm and calm evenings they often look like balls of light rolling on the surface of the water, and the more rapid their motion the more intense is the glow they emit. Those eight transparent ridges you see there," continued the doctor, as he pointed with his cane to the tiny watery globe, "support as many rows of broad, pellucid paddles, and these are all instinct with life, and by their rapid motion cause the animal to glide, meteor-like, through the waves. We wonder at the recent invention of the steam-boat, and speak with pride of the paddle-wheels with which we are to walk upon the waters; but the tiny paddles here, boy, are far more perfect than any ever contrived by human ingenuity, for in that little aqueous ball the cumbrous machinery which is required to move our vessels along, is not needed, since each float, self-moving without even a visible muscle or nerve to stir it, keeps time with all the rest."*

"What wonder," cried the poetic boy, "is here packed in a little living crystal, as it were, that can make fire flash from what looks almost like a globe of water, and that can perform the most rapid motions without, as you say, Mr. Tonkin, any visible means of movement!"

"Yes, indeed, my lad," went on the old man; "there is a large store of marvels locked in that little glassy casket. How does it get its food? How digest it? and how is its frail body nourished? for we can trace no blood-vessels, nor heart, nor glands —indeed, hardly any organs at all—in the little clot of half-liquid life. All we know, is, that it is furnished underneath with so many tentacles or filaments, that serve it for claws, and that these, which are set round an aperture that we call a mouth, draw the food it lives upon into its

* The little zoophyte here described is a kind of small "jelly-fish" known by the name of the "Beroe." It may be often seen on our shores.

body—which is literally nothing but a stomach. If we were to watch long enough, we should see the food thus seized and swallowed gradually dissolve and be reduced to a fluid state, while the more solid and indigestible portion would be rejected by the aperture through which it entered. The nutritive matter we know to be absorbed by the walls of the stomach, every part of which appears to be endowed with equal power in this respect; and it is then conveyed to the remoter portion of the body by the simple inbibition of one part from another, without any proper circulation through vessels. In some animals of this class the external covering of the body and the lining of the stomach so closely correspond in their structure as to admit of being changed one for the other—for the animal may be turned inside out without its functions being in any way deranged."

"Can it be?" said Humphry, filled with delight. "Where can I learn these things, sir? Why was I not taught them at school?"

"You *shall* learn them, my boy," replied the old man, pressing the lad's hand with pleasure to find the taste that he had longed to develope for his own favourite study springing up in Humphry's mind. "And think, if that little lump of jelly—which is, perhaps, the simplest form of life, where the vital mechanism is seen in its rudest form—can stir you to so much wonder—think, I say, Humphry, what admiration will be excited in you when you come to comprehend the beautiful processes and organism exhibited in complicate animals like ourselves! If a living, digesting creature—a thing almost without sense—a mere moving mouth—can appear so wonderful to you in its structure, what marvels shall you not find in the constitution of a thinking, speaking, reasoning being like man!"

Then the old doctor ran over to the youth the many sources of knowledge that the study of human life opens up to the thoughtful and inquiring mind.

He told the eager boy—as they sat there in the subdued light of the evening, with the hum of the sea that rippled into the caverns at the base of the Mount, falling almost musically on the ear—how, in the organism of the nerves and brain, we get our first insight, rude though it be, into the subtle processes of the senses, and even the mind itself. He told him, also, how, in the senses themselves, lay the rudiments of all the sciences; how, without the sense of vision, there could have been no "optics," and consequently no astronomy—for to the blind the movements of the planets, and even the very existence of the stars, must, of course, have remained unknown: in like manner, without the sense of hearing there could have been no "acoustics" and no music; and without the sense of muscular effort no knowledge of weight, and consequently of "gravitation"—the main-spring, as it were, of the mechanism of the universe.

Mr. Tonkin explained to the youth, moreover, that had we been formed without the exquisite organ of the hand there would have been little work done, and but little art achieved; and without the organs of the mouth, there could have been no inter-communication of thought—no transfusion of mind into mind, by which one wise man now-a-days contains stored in his own brain the wisdom of almost all those who have preceded him. And further, if we had had no appetites, and no pains nor uneasinesses to stir us to action, we should, even with the beautiful muscular apparatus with which our frames are fitted, have remained idle and inactive all our time, starving to death with delight.

"Some persons," said Mr. Tonkin, "have supposed that plants may be susceptible of feeling, as well as ourselves and the rest of the animal race. But that trees and herbs are incapable of knowing either pain or pleasure" (he added) "is made evident, physiologically, by the fact that they are supplied with no organs of locomotion, and consequently deprived of the means of avoiding the one and seeking the other. For, so benevolently is the world arranged, that wherever feeling is given, the power of acting is immediately associated with it; indeed, it requires hardly a moment's thought to perceive that it would have been incompatible with

All-Kindness to have made creatures sensible to pain, and yet have denied them the means of escape from it."

After this the old man pointed out to Humphry, that in the comparison of one system of life with another, and so tracing the delicately interwoven chain of animal creation, we perceive that the first type of sentient existence was a mere stomach—a life of pure appetite—susceptible of no other feeling than hunger, and fitted only with organs for seizing and assimilating its food; while as we advance gradually in the scale of development, we find nerve after nerve added, and a new set of feelings and actions brought out, with each new set of fibres. "We discover, besides," he continued, "that when a little kernel of nervous matter was superadded to the previous sentient apparatus, the wondrous sense of vision was first awakened in animal life, and how the addition of another such little kernel made an animal for the first time hear, and another gave the first sense of odour to the world, while another added taste to the food and drink."

And when he had thus briefly explained to the youth the uses and characteristics of the several organs in man and the lower animals, the old gentleman went on to point out to him how these same organs were nourished, and the destruction that was continually going on in the body—"for," said he, "we cannot move a muscle, not even wink our eyelids, without wasting some tissue or other"—was being as continually repaired by the food consumed. Pursuing this subject, he then proceeded to explain to young Humphry how the blood was made to circulate by means of the cunningly-wrought chambers of the heart through the veins and arteries, distributing health and vigour to the different organs in its course—now renovating the tissues, now depositing little specks of bone, then extending the filaments of hair, and then exciting thought and developing feeling in the nerves and brain, stimulating action in the muscles, and diffusing warmth throughout the whole frame—all these different functions being performed by the one wondrous substance in which, even when examined by the highest microscopic power, it was impossible to detect even the rudiments of the many various tissues it formed.

"Such," said Mr. Tonkin, "is a part of the marvellous process of secretion—a process so subtle that even the wisest can only wonder in their ignorance concerning the function; for it is a mystery to them how, by means merely of little glands, so many different things can be produced from one and the same fluid. How, for instance, skin, cartilages, muscles, hair, nails, bones, tears, and the infinite variety of products which our bodies are made up of and evolve, can all come from the same ruby stream, and that a small nut-like organ only shall be necessary to eliminate each different substance from it. Then, again, there is the beautiful process of breathing, by which the vital air is combined with the blood, and the blue fluid of the veins changed into the crimson stream of the arteries;" and he recounted to him the while how respiration among animals was merely a process of burning, accompanied with the evolution at each exhalation of so much invisible smoke from the lungs—the same smoke, indeed, as comes from burning charcoal: and he told Humphry that he would one day come to see how the rotting wood underwent precisely the same chemical change as the breathing man, and that what is a process of death and decay in the one is a process of life and health in the other.

"Indeed," concluded the old gentleman, "there is, perhaps, no sphere of knowledge so replete with wonder and beauty as that which unfolds to us the mysteries of our own existence—no science which gives us greater wisdom or deeper insight into the constitution of our natures, as well as that of the elements around us. To comprehend such a subject, even vaguely, requires an intimacy with almost every branch of learning, dealing as it does at once with the material and spiritual; while a just appreciation of the wonders it reveals cannot fail to inspire us with the highest regard for life, even in its rudest forms, and render us more keenly alive to suffering than the rest of humanity, from the greater sense it gives us of the causes of pain, while it arms us, at the same time, with the means of relieving anguish, restoring health, and often of prolonging existence.

"Some there are," he added, "who prefer poetry to philosophy; but science, Humphry, rightly understood, is merely the translation of the Great Poem of Nature—that which the Almighty himself conceived when he designed Creation. There may be high beauty in music, boy; but, to my mind, there is even higher beauty still in comprehending the phenomena by which the Creator has fitted us to enjoy it. In the rich glories of colour there is, certainly, an exquisite feast of visual delight; but what array of tints, be they ever so beautifully blended—what tracery of form, be it ever so cunningly put together—can fill the mind with ecstasy equal to the contemplation of that splendid little translucent globe, the eye—a crystal world in itself, filled with an infinity of wonders—by which we are enabled to perceive the light, and to tell one hue from another? What work of art, however consummate the execution—what picture, however choice the painting or grand the composition—what architecture, however commanding the mass or harmonious the details—and what poem, even though the verse be mellifluent as music on the water, though the imagery be luminous and profuse as the stars in winter, and the thoughts subtle as the mountain air, can bear the least comparison, either as regards the skill of its art, the craft of its design, or the nice adjustment of its parts, with the organism of the smallest animalcule fashioned by the Great Artist, Architect, and Poet of All?"

The sentence was barely finished when the sharp report of a gun rattled amidst the rocks, and Humphry, whose eyes had been turned upward as he listened to the wonders recounted by the doctor, saw the gull, which but a moment before he had noticed almost lying on the air, poised on its white outstretched wings, bound suddenly upwards with a shriek, and the instant afterwards it tumbled heavily on the crag at Mr. Tonkin's side.

The old gentleman stretched out his hand and grasped the still warm and quivering form of the bird. "If the wings of this body had been moved by some piece of curious mechanism, Humphry," he said—"if by some cunning combination of cog-wheels, and levers, and springs, it had been made to beat the air and to rise by clock-work into the sky, how would men have prized the marvellous apparatus! Monarchs would have given immense wealth to possess it: and yet the machine would have been, at best, but a clumsy toy compared with the exquisite arrangement here; for in this wonderful piece of divine mechanism the force was supplied by means of little threads of nerves that the unaided eye can scarcely trace—the movement given by muscles so beautifully elastic that no artificial fabric can imitate their play—and the bones jointed together so aptly, that when our wisest engineers wish to get movements in all directions, they can only copy their arrangement, instead of designing any such hinges for themselves. Then, again, to give lightness to the whole, these same bones were filled with air, and the living, flying machine, so made more buoyant in the thin fluid in which it was destined to soar. But let us suppose, Humphry, that it might be within the compass of art to reproduce such an apparatus as this by mechanical means; still what mechanism, however skilful, could have supplied the wonderful motive power that lately quickened it? What spring, or arrangement of weights, could imitate the action of life? Could steam even, or electricity itself, have moved the wings and guided them, like the subtle principle that stirred and directed this body only a few moments past? And then, what cunning engineery could ever have performed the function of the senses? Could mechanism have made the animal see? Could the galvanic fluid—the most spiritual, perhaps, of all our motive powers—have made it love its young, or know when to repair its strength with food? Ah! had the thoughtless fool who, for wanton sport, Humphry—who for the mere sake of hitting a moving mark in the air—known and pondered over all this, do you not think he would have found more pleasure in watching the performance of all its wondrous functions than in destroying the beautiful principle which animated them? Had he needed its body for food, hunger would have excused him. But no! It was simply the petty pleasure—the little spasm of exultation—that we derive from success in trials of skill which led him to put an end to the life of the poor bird, that had surely as much *divine* right to its place in creation as even a king himself."

Humphry was overjoyed with the lesson of kindness and wisdom he had learnt. He had been so enraptured with the knowledge that Mr. Tonkin had poured into his mind that he sat almost like one entranced, with his spirit lulled in a dream of bright things he had never heard or thought of before.

The boy till now had been more smitten with the beauty of creation than curious as to its mysteries. True, in his romantic visits to the extremity of the island, as well as to the Mount of St. Michael, he had been often led to wonder how the huge masses of rock had come there; and he had many times pondered over the origin of metals, as in his rambles he had passed the openings of the mines that perforated the surface of his native country, wondering as he went along why a vein of one ore should be deposited here, and another there. As he noticed, too, the Atlantic waves lashing the Land's End, he would repeatedly question himself as to what became of the rocks that the sea was for ever crumbling into sand; and he would form fanciful theories in his own mind, as to how the detritus of one ancient country became at last the substratum of some new one. Again, the ebbing and flowing of the ocean had led his mind to ruminate vaguely upon the mighty pulsation of the tides, while the sight of the liquid orb of the sun sinking below the ring of the horizon, away towards the invisible shores of America, had often turned his thoughts to the revolutions of the planets, and set him rudely speculating as to the source of the light and the heat of the sun itself.

Still the youth as yet had found more pleasure in contemplating the golden glories of sunset, than in seeking to comprehend the wisdom that designed them. The sea, too, to him had been more an object of grandeur than a stimulus to thought, while the sight of the rocks had filled his mind with admiration far oftener than they had quickened it with inquiry. The mystery, and even the beauty, of the principle of life, however, had never before been heeded by Humphry; so that, when he heard Mr. Tonkin relate the many wonders wrought in the changes that were continually going on in his own frame, the boy was almost overwhelmed with the flood of new thoughts that poured through his brain, and he felt as if he could have sat and listened to the old man the long night through.

Accordingly, when Mr. Tonkin came to a conclusion, Humphry begged him to proceed, saying he had begotten emotions in him that he had never known before; and he felt as if a burning thirst had come upon him for the truth, and he could drink of such knowledge for ever without quenching it.

Mr. Tonkin was pleased to find he had stirred the boy's thoughts so effectively; and he promised him that, before long, he would place him in a position where he should be able to pursue the subject as far as his powers could carry him.

Not many weeks after the above conversation, Humphry, to his exceeding delight, was articled to Mr. Bingham Borlase, the surgeon and apothecary of Penzance; and there, alone in his little chamber, at night, he wrote the following passage in his notebook:

"I have neither riches nor birth to recommend me; yet, if I live, I trust I shall not be of less service to mankind and to my friends than if I had been born with these advantages."*

* This memorable passage was written in a diary kept by Humphry Davy during his youth. His brother, after quoting it, adds, "and this early sentiment never forsook him; even in his last days he had a feeling of the same kind, looking forward, were his life spared, to greater exertions."

CHAPTER V.

THE FIRST GLIMMER OF THE SAFETY-LAMP.

HUMPHRY was hardly at home in his new quarters, when an incident occurred that directed his mind towards the investigation of one of the most subtle and mysterious principles in nature.

Mr. Borlase had returned from his day's rounds, and as he was busy unfastening the long leggings that covered his black silk stockings, he informed the family, who, with the boy, were gathered round the tea-table in the little parlour adjoining the shop, that he had heard that day of a fearful explosion which had occurred, during the last month, in one of the Welsh coal-mines.

"It seems," said the doctor, as he took his place at the table, "that there were two 'shifts,' or sets, of men employed at the pit. The first went to work at four in the morning, and were relieved by the next set at eleven; and so secure was the mine considered—so little thought of danger, indeed, entered the minds of the pitmen—that the second shift of men often entered the mine before the first had left it. This happened to be the case, they tell me, at the time of the accident; for shortly after the second set of hands had descended the shaft, the people above-ground were alarmed by a terrible report, followed by others so quickly, that it sounded like the firing of infantry, and a sheet of flame was seen to flash from the mouth of one of the shafts. The ground shook as if with an earthquake, the tremor being felt for half-a-mile round the workings; while the dull, subterranean boom of the explosion was heard, they say, nearly four miles off. Vast clouds of dust rose high in the air, in the form of an inverted cone, and large masses of timber and fragments of coal were shot straight up from the pit-mouth, as from a huge piece of artillery, and fell with a heavy crash near it; while the dust, borne by the wind, descended in a shower upwards of a mile from the spot, and as it did so, it caused a gloom, I am assured, like early twilight, in the neighbouring villages, inhabited chiefly by the families of the miners.

"The boom was no sooner heard," continued Mr. Borlase, "the tremor of the earth felt, and the darkness from the shower of ashes perceived, than the wives and children of the miners rushed frantically towards the pit. Horror and dismay were painted on every face. The crowd thickened from all sides, so that in a short time several hundreds of women and children were gathered round the shaft. The air, the people say, resounded with shrieks and cries of despair for the fate of husbands, fathers, and sons, from many a bursting heart.

"The machinery, it was then found, had been rendered useless by the explosion, so that it was near upon an hour before thirty-two persons — all that survived that dreadful catastrophe—had been brought to daylight, and of these twenty-nine only lived to relate what had occurred in the mine below.

"It was now discovered that one hundred and twenty-one, men and boys, had been in the pit when the accident happened, so that eighty-nine poor souls still remained entombed in the workings. Those who had their friends restored to them appeared, it is said, to suffer for a while as much from an excess of joy as they had, a short time before, from the depth of despair; while those who were yet in the agony of suspense filled the air with shrieks and howlings, and ran about wringing their hands and throwing their bodies into the most frantic and extravagant gestures.

"After some little time, it appears that nine persons volunteered to descend into the pit, with the faint hope that some engulfed below might still survive. As the fire-damp, however, would have been instantly ignited by candles, those who went to search the mine lighted their way by 'steel-mills,' as they are called, which," added Mr. Borlase, turning round to Humphry, "are small machines for giving light, by turning a cylinder of steel against a piece of flint; for it has been found, I should tell you, that though the fire-damp is immediately ignited by flame, it is not explosible by sparks."

The remark evidently sank deep into the boy's mind, for he knit his brows and bit his lips as if a sudden thought had flashed across his brain. But Humphry was too much interested in the narrative to interrupt the doctor, so he said not a word, and waited anxiously for Mr. Borlase to proceed.

"The men who had descended the pit," continued that gentleman, "attempted to make their way towards the spot where they knew the miners must have been at the time when the explosion happened. Their progress, however, was soon intercepted by the prevalence of what is called the 'choke-damp'—an atmosphere which it is suffocation to inhale—and the sparks from the steel-mill, they say, fell into this like dark drops of blood.

"Deprived of light, therefore, and nearly stifled, they were forced to grope their way back to the shaft.

"As each came up he was surrounded by a group of anxious inquirers, but not a ray of hope could be elicited. It was impossible, they told the people, for any breathing thing to live in the mine. At first, the assertion seemed to obtain some credit, but hope still lingered. All there recollected how persons had survived similar accidents, and stories were told how, upon opening a mine forty days after an explosion, men had been found still alive, having subsisted during the time on horse-beans and candle-ends. Then distrust began to enter the minds of the crowd, and some suggested that want of courage or bribery had induced the men who had descended to magnify the danger; so that when it was proposed by the owners to close the mouth of the pit, and so shut out the air from it—for the most experienced 'viewers' had pronounced the mine to be on fire—the proposition was received with cries of 'Murder!' and with expressions of determination to oppose such a proceeding with violence!

"All that night, they tell me," the doctor proceeded, "many of the widows lingered about the mouth of the pit, with the hope of hearing the cries of a husband or a son.

"The next morning it was again proposed to exclude the air; still the populace, made furious by their misery, would not allow the project to be carried out until some others had again descended the shaft. But none could now be found hardy enough to enter the jaws of the burning cavern. At length, however, two brave fellows were induced to make the perilous attempt, and they nearly lost their lives in so doing.

"The account given by these adventurers (for they confirmed the opinion as to the pit being on fire) ultimately convinced the people of the impossibility of their friends surviving in so deadly an atmosphere, and reconciled them to the plan of excluding the air. Accordingly the shaft was closed, with the eighty-nine poor souls entombed in it, and more than a month elapsed before the mine was opened again and in a state to admit of an examination.

"During this interval, I leave you to imagine," went on the apothecary, "what must have been the terrible suspense of those whose love made it impossible to eradicate all hope from their bosoms. The widows, anxious to believe that their husbands still lived in the closed mine, gave a ready credence to the idle tales of escape that were continually being circulated through the country. These inventions, however, had the effect of daily harrowing up afresh the sorrows of the people; so that when the morning came that had been appointed for the re-opening of the pit, the distress of the neighbourhood burst forth once more with almost redoubled fury.

"A great concourse of people assembled round the mine on that sad day: some came out of curiosity, others out of public sympathy, but the greater part came there with broken hearts and streaming eyes, intent on once more beholding the loved form of a father, brother, husband, or son.

"Soon a message was despatched for a number of coffins to be in readiness at the pit-mouth. Upwards of eighty of these had been ready prepared, and they had to pass by the miners' villages on their way to the shaft. As soon as a cart-load of them was seen, the howling of the women, who had not yet found their way to the melancholy spot, floated on the breeze in low, fitful gusts, presaging a scene of the greatest distraction and confusion; and as each load of coffins came to the pit, it brought a long train of wretched mourners in its wake.

"The bodies of the ill-fated men were found under various circumstances. One, from his position, must have been asleep when the explosion happened; others were huddled together in ghastly confusion—twenty-one were found in a heap in one spot. The power of fire was visible upon all: some were scorched; others almost torn to pieces; while others, again, appeared as if they had been stifled at their work.

"Then came the heart-rending scene," added Mr. Borlase, "of mothers and widows examining the mangled remains for marks by which to identify the bodies of their lost sons and husbands. Few, however, were able to recognise their relatives by their features; their clothes, their shoes, and—when these were too much burnt to be known again—their tobacco-boxes, or some token of affection, were often the only indications by which the lost friend could be singled out from the rest.

"Every family had made some arrangements for receiving the dead bodies of their kindred, but the doctor had very properly stated that, in his opinion, such a proceeding might spread a putrid fever through the neighbourhood, and the first body, when exposed to observation, presented so horrible and corrupt an appearance, that the people were induced to consent that each corpse should be interred as soon as it was discovered—on condition that the hearse, in its way to the chapel-yard, should pass by the door of the deceased.

"And the condition was duly complied with," concluded the doctor, solemnly. "Hour after hour, and day after day—for the finding and removal of the bodies continued for upwards of a week—the funeral carriage might be seen slowly wending its way through the half-desolate miners' villages, passing first by the door of one closed cottage, and then by another, while at the hatches of the others stood groups of women, the greater part of whom were habited in black, with little things by their side, and some with infants in their arms, mostly wearing some humble mark of mourning. As the hearse moved on, the women, with tears in their eyes, would tell one another whose body was then on its way to its last home, and each would have some little story to recite of good done and charity bestowed by the ill-fated man, while all would sigh to think what would become of the wretched widows and little orphans who, as the bier stopped at the cottage, might be seen, with streaming eyes and dejected heads, to issue forth and follow the funeral carriage slowly and sadly to the grave.

"For ten long, melancholy days," said Mr. Borlase, mournfully, "were the shutters of the houses closed in the miners' villages, and for ten days did the bell of the neighbouring chapel continually toll —for the finding of the bodies lasted all this time: and by this one terrible accident there were no less than ninety-two pitmen hurled into eternity, while as many as forty widows and one hundred and six orphan children were deprived of their protectors and ordinary means of subsistence."*

Mr. Borlase, on finishing his melancholy story, turned to Humphry, and saw the tears trickling from his cheeks.

There was a silence among all present, as if the awe of the calamity was still pressing on their hearts.

Presently the impulsive boy started to his feet

* The details of this accident are taken from the account of an explosion which occurred at Felling Colliery, near Sunderland, on the 12th of May, 1812, and of which a narrative was prefixed by the Rev. John Hodgson to the published form of the funeral sermon he preached on the occasion. It was this fearful explosion which led to the formation of the Society for the Prevention of Accidents in Coal Mines; and it was at the request of the members of this body that Humphry Davy was induced to perfect his safety-lamp.

and cried, "I'll put an end to this shocking misery, please God I will, some day."

The quick eye of young Humphry saw a smile play faintly on the doctor's lip, and he added, "I know, sir, you have reason to doubt my power to do as I say, and, perhaps, it may take me years of hard study to gain the knowledge to enable me to compass my end; but though it cost me a lifetime I will master it at last. I have sufficient faith in the goodness of the Creator, to believe that these terrible afflictions come upon us only through our ignorance, and that if we but study His will, as expressed in the laws of the universe in which He has placed us, He has given us the faculty to avert misery, and to turn the current of Nature to our own welfare rather than injury."

Mrs. Foxell (Mr. Borlase's sister), who was presiding at the tea-table, and who had already learnt to esteem Humphry highly for the generous qualities of his nature, was moved almost to tears with the benevolent impulses of the boy; for she was naturally of a kindly disposition, and the melancholy details of the accident had so affected her, that when she heard the youth vow he would one day put an end to such calamities, the transport of joy she felt was too much for her woman's heart, and though she would have cheered him on, there was an hysteric spasm in her throat that prevented her utterance for a time.

Presently the lady said, "Do not be discouraged by what my brother may say to you, Humphry. He has lived too long in the world to be as hopeful as you are, and he is so accustomed to scenes of anguish that suffering is, with him, almost an everyday occurrence. But you and I, boy, are, thank Heaven, unused to such sights, so that the mere recital of them stirs us to the depths of our natures. Besides, it is only a woman who can fully comprehend the distress wrought by such a catastrophe as my brother has recounted to us; for the real suffering in all such cases falls lighter on those who are even destroyed by it than it does upon those who are left behind. It is not so much the dead husbands I grieve for as the living widows; the lost fathers felt but a momentary pang, but the fatherless children have years of misery to pass through: and it is because my sex teaches me to understand these things deeper than yours, that I, for the sake of the poor living victims—the wives and babes, beggared in heart as well as in means—would not have a word said that would take away one spark of hope from your noble purpose. Though the prospect of success may appear barren to some minds, nevertheless if you, Humphry, can, in the ardour of your sympathy, imagine such an object to be barely possible of attainment, I say to you, Go on; and God speed you in your good work. You wish such a result to be possible, and therefore believe it to be so, and believing it, perhaps you may find it to be as you fancy; whereas if you had no faith in it you would never work at it, and consequently could never accomplish it. Think, too, if you should one day gain your end, what honour would await you—how many thousand poor creatures would hail you as their preserver—what evils you would be the means of preventing—ay, and even what wealth you might reap from such a discovery, for you could secure it to yourself, and so derive a large income from the profits of it."

"No, my good madam," replied Humphry, half indignant at the idea of enriching himself by such means, "I would never think of such a thing. My sole object would be to serve the cause of humanity, and, if I succeeded, I should be amply rewarded in the gratifying reflection of having done so. All I desire is a competence, and this, I hope, my profession will yield me; more wealth might be troublesome, and distract my attention from pursuits in which, even now, I delight. Riches," he added, "could not give me either fame or happiness; they might, undoubtedly, enable me to put four horses to my carriage, but what would it avail me to have it said that Humphry Davy drives his carriage and four?"*

* The above generous sentiments are taken, almost verbatim, from a letter of Mr. Buddle—"a person," says the biographer of our hero, "whose extensive practical knowledge justly entitled him to be considered as the highest authority on all subjects con-

The noble disinterestedness of these sentiments produced a deep impression upon all present, for they were uttered, not in the same passionate tone as that in which the boy had previously spoken, but calmly and almost gravely, as if they were the result of long reflection, and showed that the youth had already learnt to prize fame more than wealth—that his mind was bent on winning an honourable reputation rather than amassing a worldly fortune.

Old Mr. Borlase, the venerable father of Humphry's master, looked with wonder and admiration at the youth, and drawing him closely to him, exclaimed, "There's a brave lad! You remind me,

nected with the art of mining," and who was of great service to Davy in carrying out his invention of the safety-lamp. That gentleman, writing to Dr. Paris, says, "Sir Humphry Davy accompanied me into some of our fiery mines, to prove the efficacy of his lamp. Nothing could be more gratifying than the result of the experiments, as they inspired everybody with perfect confidence in the security which his invention had afforded. Sir Humphry was delighted, and I was overpowered with feelings of gratitude to the great genius which had produced it. I felt, however," continues Mr. Buddle, "that he did not contemplate any pecuniary reward, and in a private conversation I remonstrated with him on the subject. I said, 'You might as well have secured this invention by a patent, and received your five or ten thousand a-year for it.' The reply of this great and noble-minded man was, 'No, my good friend, I never thought of such a thing,'" etc. as above given. "I expostulated," adds Mr. Buddle, "saying, that his ideas were much too philosophic and refined for the occasion. He replied, 'I have enough for all my views and purposes; more wealth might be troublesome,'" and so on, the remainder of the speech being nearly word for word with that which young Humphry has been here made to deliver.

Humphry, of my poor brother the clergyman, who is dead and gone now, rest his soul!—I mean him, you know, that wrote the 'History of Cornwall;' a wonderful book it is, too!—he'd just the same notions when he was a youngster, and used to say that money was only of value for the happiness it could bring, and that there was more real pleasure to be found in seeking and discovering the truth than the richest fortune could purchase. I am sure, for my part, lad, I hope you may succeed in your noble object; and I have seen quite enough changes in my time to think nothing impossible now. Why, I have heard my grandfather say that, when he was a boy, coal itself was seldom used as fuel, and now see what wonders are being worked by it. Haven't we just had one of those wonderful steam-engines, which have been of late years invented by Mr. Watt, put up at the Wherry Mine close by?"*

The boy nodded quickly, as if he was well acquainted with the locality.

"And there," continued the old gentleman, "that great monster of brass and iron goes on, day after day

* Watt's first patent was in the year 1769, and that for his double engine was in 1781. Dr. Davy, in speaking of the Wherry Mine as being a place of favourite resort with his brother during his youth, says, "The steam-engine there (an invention," he adds, "which had only a short time before been perfected by Mr. Watt) was one of the earliest that had been introduced into Cornwall."

and night after night (though the shaft of the mine, you know, is in the sea, and the workings entirely underneath the sands), acting at a distance over the surface of the ocean, and drawing up the water from beneath its bed; and all, too, by means of a few bushels of coals. I am sure when I first saw the engine lifting up its arms, and snorting away as if with the heavy labour it was doing, it put me in mind of the old fable, I learnt at school, of Prometheus, who stole fire from the sun, you know, boy, and made men with it out of the materials of the earth. For it struck me as being a huge steam man—a kind of monster labourer, as it were, that would work on for ever, without needing any sleep, and without knowing any fatigue; and that wanted only coals, instead of bread and meat, to keep it going. Ah! we live in wonderful times, my lad, that we do; and whatever the world will come to in a few years, when I am dead and gone, is more than I can say. Why, Mrs. Foxell here was reading to me the other day, out of the 'Sherbourne Mercury,' a paragraph, saying, that a Mr.—Mr.—What was the name, my dear?"

"Symington," answered the lady appealed to.

"Yes; that's it!—Mr. Symington," proceeded the old gentleman, "had been making some experiments on the Clyde to propel a vessel, without sails or oars, over the water—what do you think of that?—and that he had actually got a large boat to move some three or four miles an hour by means of paddles worked by a steam-engine on board the vessel.* Dear, dear! What shall we come to next, I wonder! They say in the paper, too, that the experiment was perfectly successful; so that, I dare say, in a few years our sailors will be no longer at the mercy of the winds, and if they have only a stock of coals aboard, they'll be able to traverse the seas which way they like. Ah! coal is a wonderful thing, that it is, Humphry. But I'm afraid that when we sit and warm ourselves by the fire, we seldom give heed to the dangers and hardships suffered by the poor creatures who are far away under-ground, digging it out of the bowels of the earth for us."

"That's true enough," interposed the doctor, "and it's long been an opinion of mine that the greatness of England will soon depend, not so much on the energy of its people as the extent of its coal-fields. You have heard, doubtlessly, that Mr. Murdoch, in our own county here, has, within the last year or two, made a successful application of the

* W. Symington (according to Haydn's Dictionary) made a passage on the Forth and Clyde Canal in 1789. In 1807, Fulton started a steam-boat in America, on the river Hudson. In 1812, steam-vessels first began plying on the Clyde; but it was not till the year 1815 that the first steam-vessel made its appearance on the Thames. This was a boat from Glasgow; for it was only in that year the first steamer was built in England. Ten years afterward (1825) Captain Johnston received £10,000 for making the first steam voyage to India in the *Enterprise*. In the year 1852 there were 1227 steam-vessels belonging to the United Kingdom.

gas from coal to the purposes of illumination; he has produced by it a light much more brilliant than that of any lamp, and which requires no feeding nor trimming, nor has it any wick; and I am told that he speaks confidently of its being possible to light our streets and houses by such means.* But I must confess, that I myself can hardly go with the gentleman so far as that."

"Well, for my part, Bingham," interrupted the father, "I am ready to believe anything. I have lived to see mail-coaches introduced throughout the country for expediting the post, and letters that used to take near upon a fortnight to go from here to London, now carried the same distance in little more than two days.† So nothing they could do

* Gas was first evolved from coal by Clayton, in 1739. Its application to the purposes of illumination was first tried by Mr. Murdoch, in Cornwall, in 1792. Ten years after this (in 1802) Bolton and Watt's foundry, at Birmingham, exhibited the first display of gas-lights during the rejoicings for peace. The first manufactory permanently lighted by gas was a cotton mill at Manchester—this was in 1805. Gas was first used for lighting Pall Mall, in London, in 1809, and in 1814 it had become general throughout the metropolis. The gas-pipes in and round London are now said to be more than 1100 miles in length.

† Mail-coaches were first set up at Bristol, Aug. 2, 1784, and at the end of 1785 they became general in England. This plan for the conveyance of letters was the invention of Mr. Palmer, at Bath. The mails had previously been conveyed by carts with a single horse, or by boys on horseback. From the establishment of mail-coaches the prosperity of the Post-office commenced. The year before their introduction the postal revenue was only £146,000, and it ultimately increased to £2,500,000.

would astonish me after that! No, not even if I was to hear that the mail-coaches themselves were driven by coals, and at twice the rate they go at now."

This was considered so wonderful a stretch of imagination on the part of the old gentleman, that the whole company laughed heartily at the apparent impossibility of such an achievement.

"You may smile," went on the old man, "but steam is only in its infancy yet, depend upon it; and the engineer at the Wherry Mine, when I was talking to him about the machine there, told me that there was force enough in a bushel, or eighty-four pounds of coals, when properly consumed, to raise 70,000,000 pounds weight one foot high. Now, the ascent of Mont Blanc, from the valley of Chamouni, is said by travellers to be the most toilsome feat that a strong man can execute in two days; nevertheless, I find by calculation" (and the old gentleman drew a bit of paper from his waistcoat pocket) "that the combustion of only two pounds of coal would be sufficient, by means of a steam-engine, to lift a man to the summit. Again, the great Pyramid of Egypt is composed entirely of granite, it stands on eleven acres of ground, and is 500 feet high, so that its entire weight has been calculated to be about 13,000 million pounds; consequently about 180 bushels of coal would be sufficient to raise the entire mass twelve inches from its base.* So that you see, Humphry, what a wonderful thing coal is, and the large amount of force that lies locked up in every pound of it."

"I do, sir," said the boy, "and it is this which makes me wish to decrease the suffering attendant upon the working of so valuable a mineral. The account of the accident which Dr. Borlace has just told us, has so harrowed my feelings, that I shall spare neither time nor labour in seeking to discover the causes upon which such calamities depend, so as to find out the means by which to prevent them for the future. It may be some years before I shall be able to perfect my plans, but perfected they *shall* be one day if my life be spared; and then I have no fear that a discovery, having for its object the preservation of human life and the diminution of human misery, will be either neglected or forgotten. However high the gratification of possessing the good opinion of society, there is a still more exalting pleasure in the consciousness of having laboured to be useful."†

* See Sir John Herschel's "Introduction to the Study of Natural Philosophy."

† These are Davy's own words, being the concluding passage of his work "On the Safety-Lamp."

CHAPTER VI.

THE WONDERS OF HEAT: ITS SOURCES.

HUMPHRY was so full of his project, that all the day long he could think of little else, and at night he lay awake in his bed for many hours, planning an infinity of rude schemes for accomplishing the object he had in view. He devised and fashioned a number of odd contrivances, too, for the purpose, but each in its turn was found to be of little or no avail.

Nevertheless, the idea was too great to be hastily abandoned, and the sense of the fame that success in such an undertaking would assuredly give to his name had entered so deep into the boy's mind, that he got to crave more and more for worldly honours; and he would sit of an evening, alone among the rocks, dreaming of the time when he, a poor Cornish boy, was to be ranked among the intellectually noble, and reverenced throughout Europe for his genius and his benevolence.

Nor did the lad fail, when he visited his mother, to confide to her all his hopes of success and renown; and when the widow heard that he was bent on discovering the means of saving the lives of the poor miners—a class whom she had long learnt to pity, for she had been brought up in the midst of them, as it were—she felt prouder than ever of her darling boy, and shed many a tear of joy over him.

Mrs. Foxell, too, when she beheld Humphry's vexation at the repeated failures of the models he constructed, encouraged the lad in every way, reminding him that *he* himself had said the project would cost him years of hard study to accomplish.

Accordingly, after many disappointments, Humphry himself began to see that he could only hope to attain the result he desired by making himself acquainted with all that was already known upon the matter. He was ignorant even of the laws of combustion in general, and the rude experiments he had made had set his mind craving for knowledge on the subject. "Why did this thing burn, and that not?" he would inwardly inquire. "How came it that one body, as gunpowder for example, went alight all of an instant, and another, like tinder, took a long time to smoulder away? And why was phosphorous so easy to kindle, and wood, comparatively, so difficult, that the slightest friction would inflame the one, whereas it required a long time to light the other by such means? What mysterious process," he would ask himself, "went on when any substance burst into flame, and whence came the light and heat that were then given out from materials that, a few moments before, had been dark and cold? Could the light and heat have been imprisoned in the substance, and were they set free during the combustion; or were these powers generated merely by the burning of the bodies?"

Then Humphry's mind darted off to the deeper question, "What were the principles of light and heat themselves? Were they one and the same, or two distinct powers in nature? In a winter's day," he mused, "we have the same light from the sun, and but little heat; whilst in all cases of artificial illumination there is great heat and but little light, compared with that of the solar rays."

These and many other such puzzling inquiries passed through Humphry's brain, and left his mind in such a state of perplexity that he could not rest without a clearer insight into the subject. He soon saw, too, how silly he had been in setting to work before he had availed himself of the discoveries of those who had gone before him; for, he would say, how could he think of finding out, by himself, all that was known of the science of heat and light, when each of those sciences, as Mr. Tonkin had told him, had taken thousands of the wisest minds—ay, and thousands of years of intense study—to build up; for in them was contained the accumulated experience of all mankind from all time. Yet, because the truths were free to the world, he had refused to avail himself of them, and, like a proud fool, had though he could compass his end without any such knowledge at all.

It was not long before Humphry was hard at work making himself master of the laws of heat. He had borrowed of Mr. Tonkin the best book then extant upon the subject, and often when the streets of the little town in which he lived were silent as the tomb—and the distant bell of Madern Church, as it tolled the morning hours, was heard to boom upon the still air, almost like a moan—and the sound of the waves that rippled upon the neighbouring shore stole on the ear softly as the murmur of a sea-shell—the candle might be seen burning in the boy's chamber, making the little diamond panes of the casement shine like plates of amber in the darkness (for every other window in the street looked black from the want of light), while the observant eye could trace on the white wall on one side of the room, the huge distorted shadow of the lad bending over his books.

As Humphry read on, and got to see clearer and deeper into the nature and properties of the subtle principle he was studying, he grew more and more enraptured with the wonders and the knowledge that were opened up to him at every step; and often when some new discovery burst upon his mind he would, in the fervour of his admiration, fall upon his knees, there alone in his chamber at night-time, and thank God that he had come to know so much of His goodness and glory; then he would rebuke himself, too, for having remained so long ignorant of the many beauties that lay concealed in the wisdom and exquisite fitness with which the phenomena of the universe are linked together. "What fairy tale of enchantment," he would say to himself, "can display magic like this? What work of human invention can fill the mind with such amazement and delight at the subtlety of the art, as the mind feels when it first learns the wondrous story of Creation?"

When Humphry had read through the books that he had obtained of Mr. Tonkin and Mr. Borlase, he proceeded to repeat the most striking of the experiments in connexion with the subject, so as to impress the knowledge more firmly on his mind. But before doing this he reviewed the whole matter, and arranged it after his own manner—for he was not the boy to follow in a beaten track, and found no little delight in the exercise of his own genius.

"First," said Humphry, as he pondered over the science of heat in general, "*the sources of it* have to be considered; that is to say, whence is the heat of the earth derived? The universe is a vast reservoir of caloric, and it is capable of being evolved, by some means or other, from almost every substance that surrounds us; and though its production artificially is now so common that it has lost all wonder with us, there must have been a time when the elimination of it from substances on the earth must have been a matter of such amazement as to have produced a feeling of awe, on the part of the multitude, towards those who first discovered the art. This, perhaps," the boy went on, "is the origin of the fable of Prometheus, who was, probably, the first man who found out the way to kindle a fire, and so was thought to have stolen the heat from the sun. Tradition says, the first artificial fire was produced by lightning striking a decayed tree. Our minds can, even now, almost conceive the terrible awe of the people who first witnessed the liberation of fire on the earth—who beheld, for the first time, the transparent red flames burst forth from the combustible and lick the air like burning tongues, while the smoke rolled upwards from them in dense leaden clouds. Then the intense pain felt on touching the fire must have made the populace almost believe that they had been stung by demon serpents, while the roar of the wind, as it rushed towards the blazing mass to supply the place of the lighter air that had been driven upwards by it, must have sounded to the people like spectral voices, and the ultimate dissipation of the huge solid substance into invisible gases must have appeared like the most marvellous magic to them. Thus it came that men at last got to worship the fire, for its wonders and its terror, though we kindle it nowadays almost without a thought or a fear.

"The sources of heat at present known to man," continued the boy, as he wrote down the divisions of the subject in his note-book, "are many. First, there is *the heat of the sun, and, perhaps, that of the moon;* philosophers, however, have concentrated the moonbeams upwards of 300 times, by means of a burning-glass, nearly 3 feet in diameter, and yet the most delicate thermometers have shown not the least increase of temperature. This is said to arise from the feebleness of the light of the moon, as compared with that of the sun; for the lunar rays have been calculated to possess 300,000 times less illuminating power than the solar ones, whilst the light of the sun itself has been shown by experiment to have 12,000 times the intensity of the flame of a wax-candle, so that a little fragment of the great luminary the size of such a flame would possess the illuminating power of 12,000 wax-candles; and, since the diameter of the sun is nearly four times greater than the distance of the earth from the moon, this may give us some notion of the vast flood of light and (if the two are connected) of heat that are being continually streamed forth from the sun into the universe. Of the intensity of the *solar heat*, the law of the decrease of all radiant matter enables us to form some conception; for this teaches us that the heat of the sun's rays, after travelling to the distance of the earth, must be diffused over at least 300,000 times a greater space than it is at the sun itself, and consequently that the intensity of the heat must be that number of times more highly concentrated at the sun's surface than it is on reaching our atmosphere. Now, one of the largest burning mirrors that have ever been constructed, and which had the power of concentrating the sun's rays rather more than 17,000 times, melted a piece of Pompey's pillar in less than a minute, a piece of cast-iron in a quarter of a minute, a copper halfpenny in sixteen seconds, and fragments of slate and tile in three and four seconds. A lens that increased the intensity of the sun's heat about 10,000 times fused pieces of platinum, gold, asbestos, quartz, &c., in three seconds; so that—as the solar fire must, at the sun itself, be 30 times more intense than the calorific power of its rays, even when thus concentrated, at the surface of the earth—it is evident that the fury of the sun's heat must at its source be sufficient to dissipate the most obstinate metals in vapour, and to make the most infusible of the earths as liquid as glass.

"Then, again, there is the *heat of the stars;* for if each of these be suns, and they, like our own sun, give off heat, together with light, while the heat radiated by them decreases in the same proportion as their light, it is clear that the united beams of the starry host must give a certain general temperature to the realms of space. This temperature philosophers have calculated to be as low as that at which quicksilver freezes, and which degree of cold appears to be attained in the Arctic regions, during the long absence of the sun through a polar winter. According to the principles which regulate the radiation of light and heat, it is demonstrable that the starbeams can only maintain a temperature in infinite space which, when compared with the heat we derive from the sun, must be as much inferior to it as the light of a moonless midnight is to the light of midday at the equator; and it is plain, that the rate at which the earth cools down or radiates back into space the heat it receives from the sun must have its limit in the temperature of planetary space itself, so that, had this been higher or lower, the earth's surface must have been hotter or colder than it is.

"But, besides the preceding *celestial* sources of heat in nature, we must also (if we suppose that such things as give light to the earth radiate heat as well to it—though in ever so minute a degree) enumerate that peculiar cone or pyramid of luminous mist which is seen an hour or two after sunset, at certain months of the year, in the line of the ecliptic, and to which astronomers have given the name of '*the zodiacal light.*' Travellers in tropical regions tell us that this is sometimes so brilliant that it seems a second sunset, lasting almost to midnight, and that the clouds which are scattered over the deep azure of the distant horizon appear to flit past the glowing nebulosity as before a golden curtain, while above these other clouds are seen reflecting from time to time brightly variegated colours.

"Then, again, there are the brilliant coruscations of the *aurora borealis* (or '*northern dawn*,' or '*polar light*,' as it is sometimes called), though this appears to be rather an emanation from the earth itself than any celestial phenomenon. According to the best accounts, the light of the aurora exists almost within the bounds of our own atmosphere, and seems to stream from one of the poles of our globe, as if the earth had suddenly acquired the power of becoming self-luminous like the stars and sun.* This brilliant exhalation is rendered more interesting by the fact, that the great Herschel himself, from repeated observations of the spots on the sun, came to the conclusion that such spots are parts of the dark solid body of the sun itself, laid bare to our view by fluctuations in the solar atmosphere, and that from that atmosphere alone the light and heat proceed—the shining matter of the sun

* Professor Challis, of the Cambridge University, calculated the height of the bow of light proceeding from the aurora (seen at Cambridge, March 9, 1847) to be 177 miles above the surface of the earth. The limits of our own atmosphere are placed, by Sir John Herschel, at the 100th part of the diameter of the globe, or, in round numbers, 80 miles above the surface.

being, not a fluid, but a mass of brilliant or phosphoric clouds, glowing with the beams of the luminous strata of the solar atmosphere far above them—in the same manner as the aurora with us is said sometimes to illuminate a stratum of clouds below it.

"It is impossible to say what increase of heat our atmosphere may derive from the beams of the aurora and the zodiacal light, but as we have no reason for supposing the rays in these cases to be destitute of all heat, it is evident that, when enumerating the several sources of caloric in the universe, some mention should be made of them; for who can tell what would have been the effect upon the general stock of heat in nature without such phenomena, or how low the temperature of the earth's surface might have been if the heat of the planetary space in which it moves had been less than it is?

"But a far more important source of caloric to the earth lies in its *subterranean heat*, or the increase of temperature which is found to ensue as we descend below the surface of our globe. Carefully conducted experiments have shown that, in our own climate, the temperature increases about 1° for every 50 feet that we go down. At 354 feet below the ground the heat is found to be 60°, in those parts where the surface of the earth itself has a mean temperature of but 50°. At 792 feet under the soil the thermometer rises to 70°; at 1434 feet it marks 80°; at 1872 feet it reaches 90°; whereas at 2556 feet it is as high as 100°. Now, if this rate of increase (viz. 1° in every 50 odd feet) continued uniformly as we descended, it would follow that, at a depth of rather less than 2 miles, water would be constantly at the boiling point, and at 9 miles below the surface everything would be red-hot, whilst at rather more than 20 miles the granite rocks themselves would be in a continual state of fusion. In the 'United Mines' of Cornwall one of the levels is so hot, that though a stream of cold water is allowed to flow through it, in order to reduce the temperature, the miners are compelled to work nearly naked, and will bathe in water at 80° to cool themselves. At the Tresavean Mine, in the same county, which is nearly 2000 feet deep, the temperature is greater than the intensest heat of summer in the dog-days.

"There is, however, no evidence to prove that the increase of temperature beneath the surface proceeds at a uniform rate when we descend to a greater depth than 1500 feet below the level of the sea. It will be seen by the rates of increase above given that the temperature underground rises at first 1° in every 35½ feet, whereas at great depths the increase amounts only to 1° in every 68 feet; and, as far as our observations have extended, the subterranean heat appears to bear a close relation to the thermic condition of the climate at the surface; for it is found, on descending to a depth of about 60 feet in our own climate, the heat of the earth no longer fluctuates with the different seasons, but remains always at the same point during winter and summer, whilst at the tropics the stratum of invariable temperature is situate at only 1 foot below the soil.

"But whether the subterranean heat be due to the absorption of the solar rays, or whether it arises (as some have supposed) from a vast body of central fire in the earth, it is certain that we have many indications of prodigious elevations of temperature beneath the soil. These appear to be due to great chemical changes taking place in the substances forming the crust of the earth. Every schoolboy knows that a mixture of sulphur and iron-filings buried under the ground will, in a short time, become so heated as to burst into flames. Now these two materials form the mineral called 'iron pyrites,' which prevails through every coal-field, and the moisture acting on these is known to generate heat enough to inflame neighbouring combustibles—many coal-mines having been set on fire spontaneously by such means. In the 'United Mines,' where the heat is found so oppressive, it is undoubtedly owing to the decomposition of immense quantities of pyrites that are known to exist at a short distance from the works.

"Of the prodigious subterranean heat existing in some parts of the earth we have the most unmistakeable evidence. In some places boiling *hot springs*—as the Geysers of Iceland—issue from the ground (in these eggs have been cooked in 4 minutes); and even in our own country the wells of Bath have a temperature of 115°, while at those of Carlsbad, in Bohemia, the heat of the water is as high as 167°. In other parts, '*fumaroles*,' or eruptions of steam, burst from the soil; while in others there are '*solfataras*,' or jets of sulphurous vapour; and in others, again—as in the valleys of the Eifel, at the lake of Laach in Germany—'*mofettes*,' or vast exhalations of carbonic acid gas, occur. Further, there are Artesian fire-springs—like those termed '*ho-tsing*' in China, where a province has been lighted (by the gas issuing from them) for several thousand years. Moreover, eruptions of boiling acid mud, called '*salses*,' are not unfrequent. The volcano at Carguaraizo, in Peru, threw up a torrent of hot mud in the year 1698, that covered nearly 80,000 acres of ground; and in 1797, an entire village near Rio Bambo was buried under a similar mass.

"All these phenomena are evidences of intense subterranean heat, many of them being simply the products of underground combustion: but lofty jets of flame have likewise been known to blaze up from the earth, to such a height that they could be seen at a distance of 24 miles from the eruption; as, for instance, at the village of Baklichli, near Baku, on the Caspian Sea. During *earthquakes*, too, the earth has been known to open and to vomit forth flames, and gases, and enormous fragments of rocks, accompanied with a noise of subterranean thunder; while in some places the heaving soil has been inflated by the force of the compressed vapours beneath, and expanded like a bladder filled with air. Such was the case among the plains of Malpais in Mexico, in the month of September, 1759, when a tract of ground, 3 to 4 miles in extent, rose up like a huge bubble—flames bursting from the earth the while over more than half a square league—and the volcano of Jorullo being formed at the summit.

"In *volcanoes*, or burning mountains, again, we have manifestations of the intense elevation of temperature existing at certain places within the crust of the earth. The explosions from the volcano of Guacamayo, in South America, are heard almost daily at a distance of 80 miles; whilst the noise of the detonations from one in the Sunda Islands, near Java, have been distinguished 970 miles from the spot. But the most remarkable instance on record of the fury and power of the subterranean fires is to be found in the eruption of one of the Icelandic volcanoes, called 'Skaptaa Jokul,' which occurred on the 8th of June, 1783. During this eruption the large river Skaptaa entirely disappeared, and the day after, a torrent of burning lava rushed down the sides of the mountain and not only filled, but overflowed the channel of the stream, though in many places it was 600 feet deep and 200 feet broad. Then pursuing the course of the river, the fiery current poured over a lofty cataract, and filled up in a few days an enormous cavity that the waters had been hollowing out for ages. A short while after this another large river, the Hverfisfliot, disappeared from its bed, and this was filled up by another fiery torrent, which overflowed the country in one night to the extent of more than 4 miles. It has been estimated that these two streams of burning molten rocks were together 90 miles in length by 20 odd miles in breadth, and, in some places, between 500 and 600 feet deep, while there were in the aggregate forty thousand million tons of red-hot rock poured out of the bowels of the earth in the short space of ten weeks, during which the eruption lasted.*

"Another of the natural sources of heat to the earth is to be found in the *electric discharges* known under the names of forked and sheet lightning.

* To give a just idea of this fearful event it should be added, that, at the most moderate calculation, 1300 human beings lost their lives through the eruption; it likewise caused the death of 20,000 horses, 7000 horned cattle, and 130,000 sheep. The fisheries on the southern coast of the island, moreover, were destroyed by it; and Iceland has not to this day, it is said, recovered from the disastrous event of the year of the eruption of Skaptaa Jokul.

Of lightning there appear to be three kinds: (1) The *zigzag*, which is linear and sharply defined at the edges; (2) the *sheet*, which illuminates whole clouds, that seem to open and reveal the light within them; and (3) the *globular*, which appears in the form of fire-balls. The two first of these kinds last but for the thousandth part of a second, while the globular form moves much more slowly. Of the amount of heat contained in each of the different species we have no precise knowledge, though, from the experiments by which we produce discharges of electricity artificially, on a small scale, we learn that it must be considerable. If a spark which is drawn from a small Leyden jar, and which has force enough to leap only some few inches through the air, has power to inflame combustibles, and even to fuse the metals in an attenuated form, what must be the heat evolved from an electric discharge where the insulating body consists of whole acres of clouds rather than a few square inches of tin-foil, and whence the fluid has power to leap through hundreds of feet of the atmosphere towards the nearest conductor? That the electric flash possesses great heating power, we have repeated proofs; for it melts all wires that are not sufficiently substantial to allow it a free passage, inflames decayed trees, overthrows buildings, and often fuses even the rocks themselves — the tubes called '*fulgurites*,' which occur in beds of sandstone, and consist of fused sand (glass), are known to geologists to have been produced by such means—while at Funzie, in Fetlar, the lightning is recorded to have torn up a rock 105 feet long from its bed, and hurled the fragments to a considerable distance from the spot. Moreover, the electric heat is the greatest that we are enabled to produce artificially, and so much exceeds that of the strongest furnace, that platinum, which remains stubborn and infusible in a forge at a white heat, melts in the arc of flame produced by a powerful voltaic battery—like wax.

"These are the *natural* sources of heat," the youth wrote on; "the artificial methods of generating heat, however, are much more various. We can evolve heat by *mechanical* means—as, for instance, by *percussion* or *pressure.* The blacksmith hammers a nail until it becomes red-hot, and from it he lights his match; and in coining, the blank piece of metal becomes greatly heated by the sudden and violent action of the press. By the compression of air in a small tube, by means of a condensing syringe, a sufficient quantity of heat may be evolved to light German tinder; and it has been well said, 'that, locked in a pint measure of air, there exists sufficient heat to make several square inches of metal red-hot.' A piece of Indian-rubber, suddenly and forcibly drawn out, becomes warm in consequence of the extension, as may be easily perceived by applying it to the lip the moment it is stretched. Again, by the concussion of a flint and steel so much heat is produced that the sparks which fly off consist of small particles of iron that have been fused by it. Moreover, when a few grains of fulminating silver are struck by a hammer, the heat produced is sufficient to ignite gunpowder and to cause a violent explosion. Again, *friction* is a prolific source of heat. The Indian ignites two pieces of wood by rubbing them together; and even two pieces of ice may be made to melt each other by the same means. It has been truly observed, too, that an unlimited supply of heat seems capable of being derived by friction from certain materials. Water has been made to boil in two hours and a half, merely by boring into a mass of metal that was surrounded by the fluid.

"But not only can we produce heat artificially by *mechanical* means; we can do so far more plentifully and easily by *chemical* action, for it has been found, that whenever two or more substances rapidly combine, heat is invariably produced. In *fermentation* (which is nothing more than a decomposition of elements loosely united, and their reunion in a more perfect state of combination) considerable increase of temperature takes place. During the making of vinegar there is much heat evolved—the temperature rising, in some processes, from 60° to 85°. Again, in the process of respiration (which is merely the combination of the charcoal in the blood, with a certain portion of the air drawn into the lungs) the heat evolved is supposed to be the cause of our bodies remaining almost at a constant temperature. A little powder of the metal called antimony thrown into a jar of chlorine gas spontaneously ignites and burns with brilliancy, combining with the gas so readily that it takes fire and produces at first a liquid, and afterwards a soft solid called the 'butter of antimony.' Further, there is an oil-like fluid consisting of two gases (nitrogen and chlorine) that have been made to unite with each other, and this compound has such an affinity for combustible bodies, that even if a long rod, the extremity of which has been dipped in oil, be made to touch only a globule of it—the size of a mustard-seed—confined under water, it instantly explodes with a flash of light, and with such violence that it disperses the water in a shower, and breaks into atoms the vessel in which it is contained; so that experienced chemists always protect the face by a mask when making the experiment. Again, if oil of vitriol and spirits of wine, or if aqua fortis and spirits of turpentine, be suddenly mixed, sufficient heat is set free to ignite the spirits. When caustic potash, too, dissolves in water, a considerable increase of temperature ensues. So if spirits of wine and water are mixed together, the mixture becomes much hotter and occupies a smaller space; whilst if four parts of strong oil of vitriol be mixed with one part of snow or pounded ice, the heat developed is sufficient to boil water, whereas if one part of the acid be added to four parts of snow, intense cold is produced. More than this, if a piece of clean platinum be immersed in a vessel containing a mixture of oxygen and hydrogen gases, such intense heat is evolved that the metal becomes suddenly red-hot, and the gases are made to combine so rapidly that a violent explosion ensues, and the two gases become water.

"But the most ordinary mode of obtaining heat artificially is *combustion*, though this is merely a process of rapid combination after all. It is by the heat evolved during the process of combustion that our houses are warmed in winter, our food cooked, the steam-engines of our factories and mines set in motion, our metals smelted, cast, and wrought, our glass made, our dishes hardened, and an infinity of useful services rendered to us; indeed, so much do we owe to combustion, that we are unable to comprehend the state which man must have been in before the method of producing heat artificially by such means was discovered.

"Lastly, there is the heat generated by *nervous energy;* for if the sole source of warmth to the animal frame lay in the chemical processes that are continually going on within it, why should a suddenly excited emotion (as in states of anger and blushing) have power to produce so considerable an increase of temperature in the human frame? Indeed we have personal knowledge, that almost every muscular movement produces sensible warmth, even as any violent excitement of the mind is attended with the same result. We know, too, that the injury of one little thread-like nerve can reduce a member of the body to a state of stony coldness; and that after death, when the chemical decompositions are proceeding as actively as during life, the body possesses no animal heat whatever." Physiologists, moreover, have shown that, if the respiration be kept up artificially in an animal after its head has been cut off, the blood becomes arterialized, and the several chemical changes go on as during life—*but without the body being in the least warmed by them.*

CHAPTER VII.

THE WONDERFUL DIFFUSION OF HEAT.

WHEN Humphry had written thus far concerning the sources of heat (for the boy was delighted to note down his thoughts on the various subjects he was studying),* he began to ponder over the several modes in which heat was *communicated* to bodies removed from the different sources of it; for, said he to himself, "if there had been no means of propagating heat from one part of space to another, the fires could not have warmed us, and the sun would have been only a moon to our globe, while we should have been deprived of some of our most agreeable sensations. Hence, in the consideration of such a subject, it becomes necessary to at-

* The note-books of Davy during the time of his apprenticeship have been preserved, and show (says his brother) "the ardour with which he entered upon his studies, and the extensive reach of his mind in the various branches of knowledge which he proposed to pursue. One of them, bearing the date of 1795, is," (Dr. John Davy adds,) "on many accounts, a literary curiosity. It is a small quarto, with parchment covers. Outside one of the covers is the figure of an ancient lyre drawn with his pen, and on the other an olive leaf encircling a lamp; as if," remarks his biographer, "*in anticipation of his great discovery of confining*

tend to, and distinguish between, the several ways in which a body at an elevated temperature communicates its heat to others that are either in contact with it or at a distance from it, as well as the several conditions which determine the reception or absorption of the heat by different substances.

flame in the safety-lamp. At the commencement of it is the following plan of study :

1. Theology ;
   Or Religion, Ethics, or moral virtues, — Taught by Nature. / " by Revelation.
2. Geography.
3. My Profession.
   1. Botany.
   2. Pharmacy.
   3. Nosology.
   4. Anatomy.
   5. Surgery.
   6. Chemistry.
4. Logic.
5. Language.
   1. English.
   2. French.
   3. Latin.
   4. Greek.
   5. Italian.
   6. Spanish.
   7. Hebrew.
6. Physics.
   1. The doctrines and properties of natural bodies.
   2. Of the operations of nature.
   3. Of the doctrines of fluids.
   4. Of the properties of organised matter.
   5. Of the organisation of matter.
   6. Simple astronomy.
7. Mechanics.
8. Rhetoric and Oratory.
9. History and Chronology.
10. Mathematics.

To give some distinct idea of the bent of his studies at this time," continues his brother, "I shall briefly notice the principal topics which appear in this MS. volume. It opens with '*Hints towards the Investigation of Truth in Religious and Political Opinions*, composed as they occurred, to be placed in a more regular manner hereafter.' His first essay is '*On the Immortality and Immate-*

"Now, heat may be communicated from one body to another in three different ways—

1. By *emission* of rays of heat from a distance;
2. By *conduction* along the particles of a solid body;
3. By *convection* or circulation among the particles of a fluid.

riality of the Soul;' the second bears the title of '*Body, organised matter;*' and his third is '*On Governments.*' Then there follow a variety of essays on metaphysical and moral subjects. These topics occupy more than one half of the book; the other part, which appears to have been written after, commences at the opposite end, inverted. This is devoted partly to religious essays; but besides these," adds Dr. Davy, "there are some verses and the beginning of a romance, called '*An Idyl,*' which is in the form of dialogue, the characters being 'TREVELIS a warrior and friend of Prince Arthur, and MORROBIN a Druid;' the scene, 'A cliff at the Land's End in Cornwall.'

"From the same source of information—his note-books—it appears, that in the beginning of the year 1796 he entered on the study of mathematics. One book is almost entirely confined to this subject, and he seems to have finished the elementary course in more than twelve months, when he was commencing the eleventh book of Euclid, having gone through most of the other branches. He engaged in these studies without a master, and perfectly voluntary on his part, from the conviction of their usefulness preliminary to the study of chemical and physical sciences. His passion for poetry at the same time appears to have kept pace with the expansion of his faculties, and not to have been damped even by the application to mathematics, for his early note-books contain many desultory verses. His early chemical reading was confined to two works of a very different description, '*Lavoisier's Elements of Chemistry,*' and '*Nicholson's Dictionary of Chemistry.*' This new study seems very soon to have excited in his mind a most lively interest. He was not satisfied with merely reading and acquiring the ideas of others. He criticised the theoretical views of the great French

"The propagation of heat by the emission of heat-rays from a warm or burning body at a distance, is the one that first demands attention. This mode of communication is generally styled '*radiation of heat*,' and it is evident that the heat-rays emanating from one body may be communicated to another, either directly, by the process of *transmission* through the intervening substances, or indirectly, by *reflexion* from the surfaces of those opposing them; for the heat-rays, like those of light, always proceed in a straight line, and are susceptible, likewise, of being reflected or driven off at an equal angle from polished surfaces."

philosopher" (Lavoisier, the author of the new Theory of Combustion, which was propounded only some few years before); "he doubted, rejected, and advanced speculations of his own. Speculation appears to have led him to experiment, and experiment to further speculation, with such rapid progress that in a few months he had formed a new hypothesis (concerning the principle of heat), and flattered himself that he had triumphed over an important part of the doctrine of the French school.

"Humphry Davy himself writes in one of his note-books, dated 1799, 'About twenty months ago I began the study of Chemistry. The system of Lavoisier, almost the only elementary book in my possession, was the first that I studied.'" That the subject of heat was the first chemical principle that engaged the boy's attention we have further evidence in the fact, that, a few years afterwards, his "*Researches on Heat and Light*" were published in the form of essays, in a miscellaneous volume edited by Dr. Beddoes. In the preface to this work the editor says, referring to the views propounded by Davy, 'It is not necessary, in praise or excuse of his system, to add that at the time the theory was formed the author was under twenty years of age, pupil to a surgeon-apothecary in the most remote town of Cornwall, with little access to philosophical books, and none at all to philosophical men.'"

Having settled thus much in his own mind, and arranged the subject with that logical precision which was a marked feature in the genius of the youth, he proceeded to test experimentally the emissive energies, or, in other words, the radiating powers of different substances.

For this purpose he provided himself with a square tin canister: one of the four sides of this he brought to as high a polish as he possibly could; the second side he coated with a mixture of lamp-black and gum-water; over the third side he pasted a piece of paper, and the fourth he covered with glass. Then, having provided himself with a thermometer from the surgery below, he proceeded to arrange the canister at some distance from the thermometer, but on a level with it. After this he filled the canister with boiling-hot water, and then proceeded to note how the thermometer was affected when the canister was turned round, and each of its sides successively brought before the instrument. The boy soon ascertained, to his great joy, that the heat was thrown off most rapidly from the blackened side of the canister; next to that, he found the surface covered with paper to radiate heat more rapidly than the other two; then the glass side was discovered to possess more emissive power than the polished surface, while the polished surface itself had the least radiating power of all.

Delighted with the result of the experiment, and pleased with the knowledge it gave him as to the emissive energies of different substances for heat, the boy, to assure himself that he was not mistaken, held his hand at a short distance from the canister, and caused the differently-coated sides to pass successively before it. As he did so, he could feel the heat increase gradually as the polished side passed from before his hand and the blackened one came round in front of it; so that, had he not been aware of the fact, he would hardly have believed that the water in the canister was as hot at that part where the bright tin had been left as it was where the side had been blackened over.

Next the lad tried another modification of the same experiment. Having blackened one canister entirely over, and brightly polished the outside of another which was of the same size, he filled the two vessels with boiling water, and putting a thermometer into each he placed them upon a table at opposite corners of an empty room, and then found that the thermometer in the blackened vessel fell much quicker than that in the polished tin one; so he now saw that the reason why the *black* side of the canister in the first experiment felt hotter than the *polished* surface did to his hand was, that the water there was parting with its heat at a more rapid rate, so that in the entirely blackened vessel it necessarily cooled down sooner than in the bright tin one.

Humphry was so delighted with the truths he had thus discovered, that he tried a number of other experiments as to the radiating power of different substances, and at last came to the conclusion that lamp-black, sealing-wax, wool, paper, glass, and black-lead, were much better radiators of heat than the metals; their power of giving off heat being in the order in which they are here mentioned—a surface of lamp-black cooling quicker than one of sealing-wax, and sealing-wax again more rapidly than writing-paper, and so on down to the metals, which cooled the slowest of all.

Then, having dealt with *different* substances, the youth set to work to ascertain what effect an alteration in the arrangement of the surface produced in the radiating power of the *same* substance. Accordingly he tarnished, by means of acid, one of the sides of the polished tin canister he had previously employed, and found, on filling the vessel again with hot water, that the *dulled* surface parted with its heat quicker than the *bright* one. After this, he proceeded to roughen another of the sides with some emery paper, and then, on re-filling the vessel, he discovered that the scratched surface cooled at a greater rate than the smooth polished one.

"So, then," said young Humphry to himself, "not only have *different* substances various radiating powers for heat, but also a difference in the arrangement of the surface of the *same* substance is attended with a like effect."

Still the lad had to examine the result produced by bodies of *different densities*, and this he did by means of a vessel of cast-iron and one of wrought-iron, when he found that the *cast* metal parted with its heat quicker than the hammered or *wrought* metal; so that it was evident a *lighter* material was a better radiator of caloric than a *heavier* one—for the particles of the iron in being wrought had been brought closer together, and the metal thus rendered of greater density.

This done, Humphry made an entry in his note-book, "that not only did rough or dull surfaces part with their heat quicker than smooth or bright surfaces, but that light bodies were better radiators than heavy ones."

The young experimentalist was overjoyed with the progress he had made, and he would have rambled off into a number of speculations as to the effect which the principles he had discovered must produce in nature (for he saw that the different surfaces of different countries must yield a like result); but he was too intent on pursuing the investigations he had undertaken to allow himself, yet awhile, to apply them to the explanation of terrestrial phenomena. Moreover, he had still to learn the different rates of cooling among bodies in the air and in a vacuum. To do this, however, an air-pump was necessary, and how he was to obtain such an apparatus puzzled his ingenuity for a considerable time.

At length the youth remembered to have seen a large syringe among Mr. Tonkin's instruments, and having obtained the loan of this, he applied it to a stand, and used it as the pump for extracting the air from the receiver. When the instrument was complete, Humphry found that bodies which took between two and three minutes to cool in the air were as long as five minutes in parting with the same quantity of heat in a vessel from which all the air had been exhausted. So he now perceived, that the same substances gave off their heat twice as quick in the *open air* as they did *in vacuo*.

The next step was to ascertain the different amounts of radiation among different bodies on the earth. For this purpose the boy borrowed as many thermometers as he could procure among his friends in the town; and early one evening, after the sun had declined, and when the soil was parting with the heat it had received in the course of the day, he proceeded to test, by means of the instruments, the several rates at which the various substances upon the earth were being cooled down. One of the thermometers he suspended in the air four feet above the grass-plat in the garden at the back of the doctor's house; another he placed on some wool which he had spread on a raised board; another he deposited on the surface of the raised board itself;

and a fourth he rested on the grass-plat. Shortly afterwards he proceeded to note the temperatures indicated by the several thermometers in the different situations, when he found that the one in the air stood at rather more than 60°, while that resting on the wool was at 54½°, and that lying on the board at 57°, whereas the one on the grass-plat marked only 51°. In an hour or two after this, the boy noticed that the blades of grass were suffused with dew, and that the fibres of the wool also were beaded over with little drops of moisture, but to a less extent than the grass, while the surface of the board remained almost dry.

"So then," he said to himself, "*wool* is a better radiator than *wood*, and, cooling quicker, condenses the moisture of the air more rapidly upon it; but *grass* again, as the thermometer showed, cooled quicker even than the wool, and therefore collects more dew than either."

This induced young Humphry to try another experiment, in order to ascertain whether those bodies which cooled most rapidly collected the most dew on their surfaces. Accordingly he placed a piece of bright polished metal and a piece of glass (for the surfaces of these substances were nearly the same) on the gravel-path, and was delighted to perceive that in a short time the *glass* was covered with moisture while the *metal* remained perfectly dry. A strip of *flannel* was then put beside the other two, and, being a good radiator, it soon became spotted with dew-drops. After this the boy coated the piece of polished metal with lamp-black, and found it *then*, like the others, capable of condensing the moisture of the air upon its surface.

"It is as I expected," cried the lad; "the dew which the ancients imagined to be shed from the stars is simply the condensation of the vapour in the atmosphere upon cold surfaces; and, consequently, those bodies which have the greatest radiating power, and so become cold the quickest, are found to have the largest deposition of dew formed upon them, while those which, like polished metals, part with their heat but slowly, and so remain for a long time at the same temperature, have but little moisture condensed upon their surface. The deposition of dew," he went on musing, "is precisely similar to the condensation of moisture that occurs on the outside of a bottle of very cold water when brought into a warm room. The cold surface of the glass abstracts heat from the vapour in the air of the apartment, and so causes it to be condensed in the form of little watery globules on the surface. In the same manner the earth, parting at night with the heat it has received during the day from the sun, becomes cooler than the atmosphere above it —for thermometers show, that when the grass is at 51° in the evening, the air only four feet above it is more than 60°—and accordingly the cold surface of the blades acts upon the vapour in the atmosphere, precisely the same as the outside of the cold bottle does upon the air in a warm room."

So pleased was the lad with the insight that his investigations had given him into some of the mysteries of nature, that he continued his experiments on this subject for many nights; and in the course of these he found, that not only had different bodies different dew-collecting powers, but that different colours even possessed the same property; for on exposing a piece of yellow, of green, of red, and of black glass to the night air, he perceived that the moisture appeared first on the *yellow* glass, then on the *green*, but that none at all showed itself on either the *red* or *black* glasses.

To his astonishment, however, he at length discovered, that when the evenings were *cloudy*, and there seemed to be a greater quantity of moisture in the atmosphere, the pieces of flannel and glass, and little piles of swan's-down with which he had studded the gravel-walk, remained unmoistened with dew; whereas, when the nights were *clear* and apparently *dry*, they, one and all, with the exception of the polished metals, became rapidly suffused with moisture. This for awhile entirely baffled the boy's comprehension. "How came it that more dew was deposited on dry clear nights than on dull damp ones?" Surely, such being the case, the dew cannot be said to proceed from the vapour in the atmosphere; for if it does, reasoned Humphry, it is evident that when there is more moisture in the air there should be more dew deposited on the earth.

At length it struck the boy that, perhaps, the clouds themselves might interfere in some way or other with the result; so the next fine clear night he strewed the gravel-walk, as before, with fragments of such substances as he had already found to be the best collectors of dew; and then, at the other end of the path, he placed pieces of the same substances under a small awning, which he made out of his pocket-handkerchief, fastened at each corner to a short stick. This he did in order to see what effect would be produced by *screening* bodies from the sky—since the clouds, he fancied, might act in some such manner.

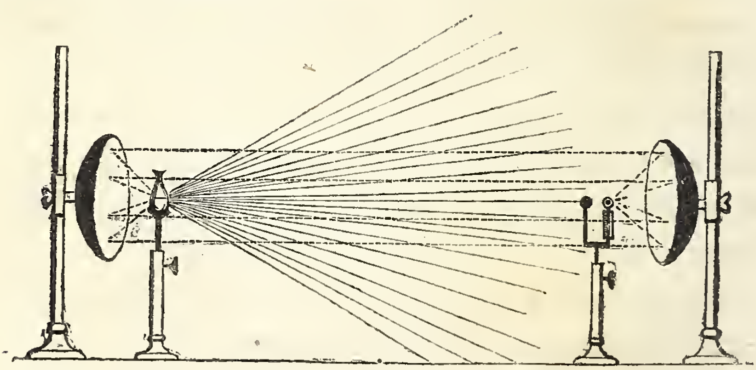
On returning to the garden after a short interval, Humphry was rejoiced to find that there was a copious deposition of dew on the pieces of glass and wool that he had left *exposed* to the sky, while the surfaces of those which were *screened* by the little awning above them remained perfectly dry.

"Yes," cried the lad, "the clouds *do* act as screens. They give back, perhaps, some of the heat that the earth at night is radiating into space, and so prevent bodies cooling down as rapidly as they otherwise would."

However, to satisfy himself that the clouds really *did* interfere with the radiation of bodies on the earth, Humphry arranged an apparatus for testing the point. This consisted of a thermometer, the bulb of which was first incased in wool (for that substance he knew to part readily with heat) and afterwards fixed in the focus of a small concave mirror. Then on the next windy night, when the clouds were drifting swiftly across the sky—leaving the heavens occasionally clear, and occasionally hiding the light of the stars—the anxious lad turned the mirror towards the blue vault above, and, on doing so, he could hardly repress his glee as he beheld the quicksilver in the tube of the thermometer descend and ascend, each time the sky became clear or clouded. Though, by means of another thermometer, he knew the temperature of the surrounding atmosphere to be 60°, Humphry nevertheless found that, when the sky was *unclouded*, the mercury in the one attached to the mirror indicated only 45°, whilst immediately that a *cloud passed over the firmament*, and so prevented the bulb from parting with its heat, the quicksilver rose rapidly again to the temperature of the air around. So intensely did Humphry exult in the result of this experiment, that he remained long, watching the thermometer rise and fall, as the clouds swept one after another across the sky.

The next day, Humphry, now that he had made himself acquainted with the circumstances that regulated the *emission* or radiation of heat from bodies, began to turn his attention to the *reflexion* of it from such substances as impeded the progress of the rays; "for," said he, "if bodies at an elevated temperature have the power of sending out rays of heat in all directions—in the same manner as luminous bodies emit rays of light—it follows that substances opposing the passage of the heat-rays must either *absorb* them, and so become heated themselves—or they must *transmit* them and so allow the rays to proceed in their original direction—or else they must *reflect* them and so bend them into another course."

For the study of the *reflexion* of heat the lad procured two concave mirrors, made of tin-plate and about 1 foot in diameter. These he arranged so as to slide up and down a pillar, to which they were respectively attached. Thus provided, Humphry proceeded to place a small "Florence flask," filled with hot water, in the focus of one of the mirrors, while in the other focus he arranged a thermometer after this fashion:

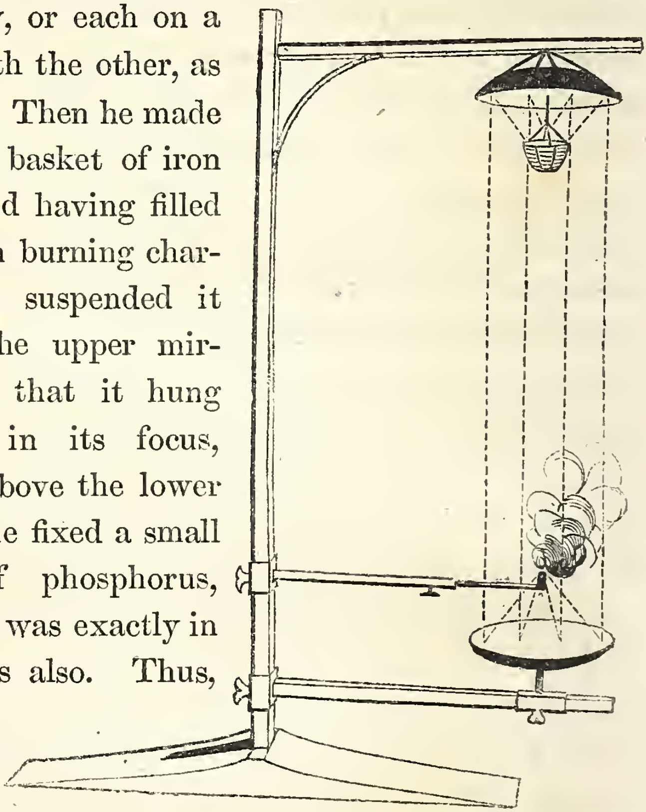


Now, though the mirrors were some feet apart, the mercury in the tube, to the boy's great delight, rose almost to the heat of the boiling water in the flask.

After a few moments' reflection, the lad fancied the effect might perhaps be due to the radiation of the heat from the flask itself, rather than to the reflexion of it from the mirrors. So, to satisfy himself whether or not such were the case, he placed a sheet of pasteboard immediately in front of the mirror near the thermometer, and thus prevented any rays being reflected from the one to the other. No sooner, however, had he done so than the mercury was seen to fall in the tube—even though the source of heat was as near to the thermometer as before; but directly he removed the pasteboard from between the mirror and the thermometer, the quicksilver rose rapidly again, and stood at the same number of degrees as it previously did.

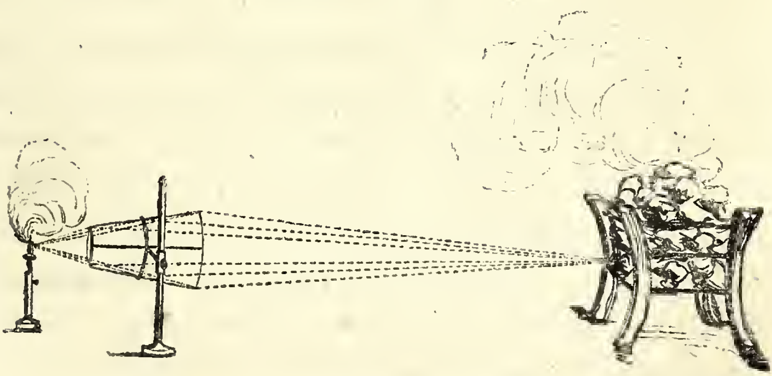
Having convinced himself upon this point, he then drew the thermometer away from the focus and nearer to the heated flask, so that, if the effect were due to radiation, the mercury, as it approached the source of heat, should rise higher in the tube. The contrary result, however, was found to ensue; and it will be seen on reference to the preceding engraving, that by *radiation* only a few of the heat-rays (which are indicated by the diverging *unbroken* lines) would fall upon the thermometer, whereas by *reflexion* a much larger number of such rays become concentrated upon the bulb in the focus of the opposite mirror—as shown by the *dotted* lines in the diagram.

Humphry was now anxious to see whether, by reflexion of the heat-rays, he could ignite combustible bodies at a distance; but for this purpose he changed the situation of the mirrors, arranging them vertically one above the other, instead of horizontally, or each on a level with the other, as before. Then he made a small basket of iron wire, and having filled this with burning charcoal, he suspended it below the upper mirror, so that it hung exactly in its focus, whilst above the lower mirror he fixed a small piece of phosphorus, and this was exactly in the focus also. Thus, on the completion of



the arrangement, the boy was as astonished as he was delighted to perceive that the phosphorus was immediately inflamed by the *reflected* rays of heat. Some fulminating silver was then exploded in like manner. After this Humphry boiled some water in a flask that he substituted for the piece of phosphorus in the focus of the lower mirror, and finally cooked a chop, by the same means, at some considerable distance from the fire.

Next, instead of the two mirrors, he rolled up a sheet of bright gilt paper, with the metallic side inwards, into the form of a long cone or funnel, so that the opening was larger at one end than at the other; then holding the larger end towards a clear fire, he found the rays of heat were concentrated into a focus at a little distance beyond the smaller end, and there he caused a bit of phosphorus again to inflame, by means of the reflected heat. The subjoined diagram exhibits the arrangement.*



Humphry now began to wonder what effect would

* A lucifer match may be conveniently employed for the same purpose, and it will be found that the match, by means of the cone, may be inflamed at a greater distance from the fire than it could possibly be without it.

be produced by a piece of ice placed in the focus of one of the mirrors; and he thought for a long time whether the rays of *cold* would be reflected from the ice, as those of *heat* had been from the hot water and the burning charcoal. As the winter had long set in, he found no difficulty in obtaining such a piece as he required from one of the neighbouring ponds, and then arranging the mirrors as before, he placed it in the focus of one of them, while in that of the other he fixed the thermometer which he had previously employed.

To the lad's astonishment he discovered that the mercury immediately began to fall, and at length stood at 32°, or the freezing point. "So then!" he cried, "it *is* possible to reflect rays of *cold* as well as those of *heat*. And yet," said he to himself, after musing for a while, "*is* it the ice, after all, that is radiating *cold* to the thermometer, or the thermometer itself, which, being warmer than the frozen water, is really and truly radiating *heat* to the ice?" If, instead of the thermometer, he had placed a red-hot body in the one focus, while the ice remained in the other, Humphry knew well enough that the warmer body, as it became cool, would be giving off heat to the colder one. "Why then," he asked himself, "should he fancy that the thermometer itself—because it was *only a few degrees warmer than the ice*—lacked the power of parting with its heat to the colder body, in the same manner as the red-hot charcoal?"

The lad was soon convinced of his previous fallacy; and when he saw that the apparently contradictory effect was no anomaly after all, he could hardly refrain from smiling at the simplicity which had led him to believe at first that rays of cold were reflected from the ice to the thermometer, instead of the rays of heat being given off by the thermometer to the ice.

As yet, however, Humphry had experimented concerning the *reflexion* of heat with mirrors only of *polished metal;* and one day, when he was recounting to Mr. Tonkin the curious effects he had produced, the old gentleman asked the lad what he imagined would have been the effect if, instead of *metal* mirrors, he had used *glass* ones.

Humphry answered confidently, that, as the results were due only to the reflexion of the rays from the concave surface, a glass mirror, *of course,* would have given precisely the same effects as the metal ones.

"Try it," was all the old man said, as he smiled at the positiveness of the boy's reply.

Nor was the young experimentalist long in doing so, for he saw by Mr. Tonkin's manner that some strange difference in the effect would ensue—though for the life of him he could not divine what it was to be.

Accordingly, at the earliest opportunity, the boy substituted the glass concave mirror, which Mr.

Tonkin had lent him for the purpose, for one of the metal ones which he had previously employed; then filling the little wire basket with red-hot charcoal, as before, and hanging it in the focus of the upper mirror, he once more suspended a piece of phosphorus in the focus of the lower mirror, which was now of *glass instead of metal.* To his utter amazement, however, the phosphorus was no longer capable of being inflamed in such a manner.

It was but the work of a moment to remove the combustible from the focus of the glass mirror, and to place a thermometer there in its stead; and this soon showed that there was now *little, if any,* heat reflected.

"How wonderful!" cried the startled boy. "What *can* be the cause of it? I'll arrange the mirrors differently," he added, "and see if I can find it out."

But no sooner did Humphry put his finger on the glass than he drew it suddenly back, as he exclaimed, "How hot the lower mirror has become! and I remember when I used the metal one, that I was surprised to find, on removing it, though the heat was sufficient to boil water and ignite bodies in its focus, the metal surface of the mirror itself was scarcely warmed. But now that *glass* is used," he went on, "*the mirror itself is rendered hot, while in the focus of it there is scarcely any*

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perceptible increase of temperature. So, then," he added, "the glass *absorbs* the heat-rays, and therefore does *not reflect* them, while the metal on the other hand *reflects*, because it does *not absorb* them. Still it's very strange," mused Humphry, as he proceeded to blacken a small card, "for the glass mirror must *reflect* the *light* of the fire, though it *absorbs* the *heat* from it. I'll try whether such is the case or not."

The card was then placed in the focus, and a bright spot of light was seen shining like silver in the centre of the blackened surface.

"Yes," cried the lad, "it reflects the light, but not the heat of the fire. How strange! I wonder whether the same effect would be produced by the sun's rays!"

Accordingly the next day, when the sun was shining brightly, Humphry arranged the mirror in the garden, so that the beams might be concentrated in its focus; and then, to his greater astonishment, he found that he could inflame combustibles by the *solar* heat with the *glass* mirror, in the same manner as he had previously done by *artificial* heat with the *metal* ones.

"The *light and heat* of the sun, then," said Humphry, as he stood watching the white fumes of the burning phosphorus rise in the air, "are capable of being reflected by glass, whereas the *light only* of an artificial fire can be concentrated into a focus by it—the heat in the latter case being absorbed."

The metal mirror, likewise, was found to possess the power of reflecting both the solar light and heat, in the same manner as it had been before made to reflect both the light and heat of an artificial fire.

The experiment with the glass mirror, however, clearly showed that solar heat differed in some way or other from terrestrial heat; but *how*, was a source of continual wonder to the lad.

From the *reflexion* of heat, Humphry proceeded to the *transmission* of it.

Light passes readily through certain substances, which are therefore said to be *transparent*, while others impede the progress of the beams, and are consequently called *opaque*. "Is there, then," mused the boy, "such a property as *transparence* and *opacity* for *heat*, as well as light, among bodies? Are some substances *pellucid*, as it were, to heat like they are to light? and are some as impermeable to the one as they are to the other?"

The lad knew well that the heat of the sun was capable of being transmitted through glass as well as its light, for he had often concentrated the solar beams by means of a magnifying or "burning" lens, as it is called: glass, therefore, was transparent to the *solar* heat as well as light; but was it so to the rays of *artificial* heat?

To ascertain this, Humphry borrowed old Dr. Tonkin's large reading lens, and held it before the fire so that the focus fell upon the bulb of a thermometer. But though the light of the burning coals was seen concentrated into a bright spot upon the bulb, still the mercury in the tube gave no indications of any increase of temperature. The lens, however, which was scarcely warmed when the sun's rays passed through it, became greatly heated when the rays of the artificial fire were made to fall upon it—thus showing, that while it *transmitted* the solar heat it *absorbed* the terrestrial.

It was evident, therefore, that though the *heat of the sun* has the power of passing freely through glass, *artificial heat*, on the other hand, is completely stopped by it.

Humphry then thought he should like to try the effect of a piece of black glass, for this would be perfectly opaque to light, and he longed much to see whether it would be equally impermeable to heat. On holding a square piece before the fire, the boy was surprised to perceive the thermometer he had arranged behind it rise rapidly, thus showing that though black glass was *in-transparent to light*, it was by no means *opaque to heat*. That the quicksilver was made to mount in the tube solely by the influence of the heat-rays which traversed the black glass—and not by any indirect radiation from the fire—Humphry assured himself, by placing a piece of white glass, of the same size and thickness as the black one, before the thermometer: the quicksilver, however, was immediately seen to fall. "How marvellous is this!" he exclaimed. "Light and heat, then, are capable of being separated one from the other; and there are bodies in nature which, like *white* glass, are *transparent* to light, but *opaque* to heat; while there are others, like *black* glass, that allow the heat-rays to *pass through* them, though they are *incapable of being traversed* by the luminous ones."

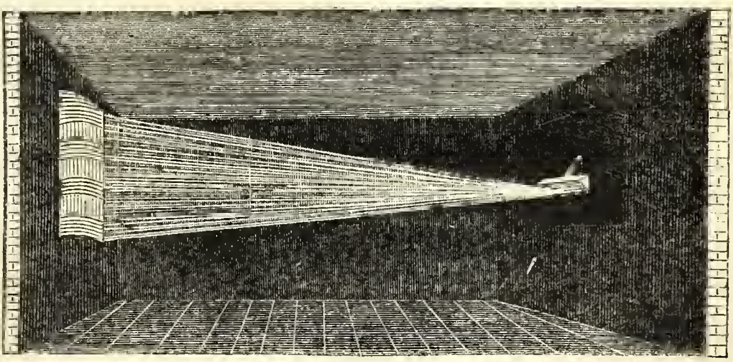
The boy was so full of the new truth that had thus become impressed upon his mind, that he hurried off to Mr. Tonkin to confer with him on the result. From him Humphry learnt that there were other substances, besides glass, that gave equally curious effects—the most striking of these, the old gentleman told the boy, were *alum* and *rock-salt*, for though both were transparent to light, they had by no means the same power of transmitting heat; for it would be found that while a small plate of rock-salt allowed the rays of heat to pass almost *freely* through it, a similar plate of alum was nearly *impermeable* to them.

The young philosopher was not long in trying the experiment. Having procured two such plates as Mr. Tonkin had advised, he used them as small screens in front of the fire, and found that a thermometer behind the rock-salt rose rapidly; whereas, behind the alum, it was scarcely affected, for the heat was nearly all stopped by it.

The possibility of separating heat from light made a powerful impression upon the ardent boy, and he wondered whether he could arrive at the same result with the solar beams as he had with the rays of an artificial fire. For a long time he pondered over the matter, and conceived and tried a number of fruitless experiments in connexion with it.

At length, however, he remembered to have read somewhere, that by means of a glass prism the beam of white light proceeding from the sun might be separated into all the colours of the rainbow.

Accordingly he set to work to repeat the experiment. Having darkened his room he made a hole in the window-shutter, and placed behind it a glass prism, with one of the sharp edges downwards and one of the flat sides uppermost, as shown in the annexed illustration:



Immediately that the arrangement was complete, and the beam from without fell on the glass within, the wall on the opposite side was iridescent with a strip of variegated light, as if a slice of a bright rainbow were clinging to it. The lower end of the luminous band was a rich warm red, and this passed, by a tint of orange, into a bright yellow, which again died away, by deepening hues of green, into a narrow strip of dark blue, while, at the upper end, the indigo tint became warmed into a brilliant edging of violet.

When the rapture of the boy on first beholding the sight had, in a measure, subsided, he proceeded, by means of a thermometer, to ascertain the temperature of the several rays. First he tried the upper end of the spectrum, and found that in the *blue* ray the mercury marked 56°. Then passing downwards Humphry was overjoyed to see the quicksilver mount as he proceeded towards the middle, where, in the *yellow* ray, the instrument indicated a temperature of 62°, *i. e.* 6° higher than in the blue; while at the lower end—at the extremity of the *red* ray—the temperature was found to be as high as 79°, *i. e.* 17° higher than it was in the yellow.

There was then, altogether, as much as 33° difference between the heat at the extreme ends of the luminous band—the *red* ray being upwards of half as hot again as the *blue* one—so that light and heat were capable of being separated even in the solar beams themselves; for the yellow contained the most light of all, and yet it was 17° colder than the extreme verge of the red ray, where there was only a faint luminous blush to be perceived.

The next step was to ascertain the circumstances regulating the *reception* or *absorption* of heat.

Humphry had now investigated the laws which governed the radiation or *emission* of the rays of heat from bodies at an elevated temperature. He had ascertained that these rays not only emanated from heated substances at different rates, and so caused them to cool down more or less rapidly, but that—though their tendency was to proceed, like the rays of light, in a straight line—they were capable of being *reflected* or bent back by certain bodies opposing their progress, and that in such cases the reflecting bodies themselves did not become heated by them. Other bodies, again, he had found to have the power of *transmitting* the rays of heat, that is to say, of allowing them to pass *through* their substance rather than reflecting or driving them *back* from their surface; and such transmitting bodies, moreover, were likewise scarcely warmed by the heat that traversed them. Now he was about to investigate the conditions that determined the *absorption* of the heat-rays, by bodies upon which they fell after being given off by *radiation* from others of a higher temperature.

The lad's first experiment upon this subject was to blacken the surface of one of the metal mirrors that he had previously found to reflect the heat, without being itself warmed in so doing.

The result proved to be as Humphry had anticipated. The mirror no longer had the power of concentrating the heat in a focus, at a short distance in front of it: for now, instead of *reflecting* the rays and remaining *cool* as before, it *absorbed* all the heat that fell upon it, and became itself *warmed* by the neighbouring radiator.

The same effect ensued when the surface of the mirror was whitened with chalk, and the same again when it was roughened, or scratched, with emery paper: so that *rough* and *dull* bodies proved to be better absorbers of heat—even as they were better radiators—than *bright* or *polished* ones.

Hence there appeared to be some connexion between the radiating and absorbing powers of different substances—those which cool the quickest seeming to be capable, also, of being heated in the shortest time.

To test this the lad placed a blackened and a bright-polished vessel in front of the fire, and found that the thermometer in the *black* vessel rose much more rapidly than did that in the *bright* one.

Humphry then availed himself of these two vessels as a means of testing the relation between the *absorbing* and *radiating* powers of black and bright-polished surfaces. Into the mouths of the black and the bright tin vessel he inserted a thermometer, and then placed between them one of the square canisters he had previously employed, and which, it will be remembered, had one of its sides bright, while the opposite one was coated with lamp-black.

Having filled the middle canister with boiling-hot water, he proceeded first to note the radiating and absorbing effects when the *different* surfaces were opposed to each other. On arranging the middle canister so that its black side was turned towards the polished vessel at one end, and its polished side to the blackened vessel at the other end, there was no effect produced upon either of the thermometers; for then the opposite powers of the *different* surfaces exactly balanced each other. When, however, the apparatus was so adjusted that *similar* surfaces were opposed—that is to say, so that the blackened side of the canister in the middle was turned towards the black vessel, and the bright-polished side to the bright-polished vessel — the thermometer in the black vessel immediately indicated a great excess of heat; for then not only was there a *good radiator* opposed to a *good absorber*, but, on the other side, the two bright surfaces were facing each other—that is, the *bad radiator* was turned towards the *bad absorber*—so that even the little heat which was given off from the polished side of the canister was driven back again to it by the surface of the neighbouring bright vessel. Hence everything *favoured* the radiation and absorption of the heat on the one side, where black was opposed to black, and *prevented* it on the other, where metal was facing metal; and thus the great elevation of the thermometer was accounted for.

As it was now winter time and the snow lay thick upon the earth, Humphry availed himself of the circumstance to test the absorbing powers of different *colours*. For this purpose he took a number of pieces of different coloured cloths, and placing them at mid-day upon the snow, so that the sun's rays could fall directly upon them, he found that the *dark* colours sank the deepest into the frozen mass beneath, while the *lighter* hues produced scarcely any thawing effect, and the *white* remained utterly inactive.

The same result was obtained by means of coloured glasses; for against a window-pane that was covered with hoar-frost the lad placed some pieces of black, red, green, and yellow glass, and the consequence was, that the ice opposite to the *black* and *red* pieces was melted long before any thawing effect was visible upon the frozen film screened by the other colours.

When the weather grew warm Humphry obtained another very curious illustration of the power of black substances to absorb the heat of the sun's rays. Having filled a glass tube with spirits of wine, he placed it in the focus of a lens, and found that the solar heat traversed the transparent liquid without warming it. On immersing a small piece of charcoal, however, in the alcohol, so great was the absorptive power of the *black* surface that the fluid immediately began to boil. By the same means, too, he succeeded in raising the temperature of water to the boiling point. This showed that water, as well as spirits of wine, was a good *transmitter* and bad *absorber* of heat; that is to say, that the rays passed freely through each without warming either, unless some substance were immersed in the liquid in order to detain and absorb their heat.

Air, on the other hand, the boy knew to have little or no heat-absorbing power; for the rays emitted by a distant hot body traversed the atmosphere without sensibly raising its temperature. He had read, too, that philosophers had calculated that only one-fifth of the solar heat was absorbed in passing through 1000 feet of the air, and that but one-third of the entire heat of the sun was taken up by the passage of the beams through the whole atmosphere.

Humphry, moreover, sought to discover whether the sun's heat, reflected from a mirror, would produce the same effect as the direct solar beams. Accordingly, before the winter passed away, he placed two pieces of blackened card upon the snow, at a considerable distance apart. One of these he left exposed to the *direct* rays of the sun, while upon the other he caused the sun-beams to fall *indirectly*, by reflecting them from a polished metal surface. The black card that was submitted to the direct solar beams sank, after a little time, deep into the snow, while the frozen mass around—though the beams fell full upon it—was but slightly thawed. With the black card, however, upon which the sun's rays were *reflected*, a precisely opposite result ensued. In that case the surrounding snow itself was the first to melt, while the blackened surface seemed to have been deprived of its power of absorbing heat, and remained high on the unthawed pile beneath it.

Further, Humphry noticed that the snow which lay near the trunks of trees, or wooden posts, melted much sooner than that which was at a distance from them, and that the thawing always commenced at the side facing the sun. Hence it was evident that the solar heat, after being either *reflected* or *radiated* from bodies on the earth, and so made to fall *indirectly* upon other bodies, was rendered capable of being absorbed by substances which, like snow, had but little or no power of being warmed by it *directly*.

Why this should be, or what alteration the solar rays underwent in impinging upon terrestrial bodies, so that substances which before absorbed the sun's heat with difficulty became afterwards more easily warmed by it, was more than Humphry's philosophy could explain—though it cost him many a day's hard thinking in trying to account for the result.

Having now investigated the conditions which governed the diffusion of heat from a *distant* point, Humphry next proceeded to inquire into the circumstances which regulated the communication of heat to bodies in *contact* with others at an elevated temperature.

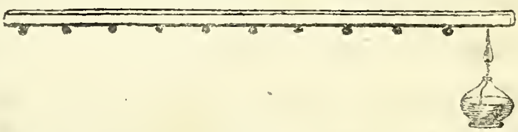
This constitutes what is called the *conduction* of caloric, and occurs between different bodies, or parts of the same body, immediately adjoining each other. The communication of heat by *conduction* is a slow process compared with that of *radiation*, which is, probably, as rapid as the diffusion of light itself. Philosophers have calculated, that even if the crust of the earth were made of cast-iron (which is a much better conductor than rocks and stones), it would take myriads of years to transfer the heat from a depth of 150 miles below the surface to the surface itself; whereas by radiation the solar heat travels from the sun to us in 8½ minutes.

The laws which regulate the communication of caloric to *distant* objects are similar to those which would ensue if the heat really consisted of so many hot particles darted out from the heated body in all directions; and colder bodies placed in the neighbourhood of heated ones, either become hot in the same manner *as they would if* such particles were positively absorbed by them, and entered into their substance; or they *reflect* the heat to other bodies, while they themselves are unwarmed by it—*as if* (according to the hypothesis) the caloric particles were elastic, and had the power of bounding off from smooth surfaces interfering with their progress; or else they *transmit* the heat rays, *as if* the imaginary particles of caloric were capable of freely traversing certain substances, and that, also, without sensibly raising the temperature of the permeated mass.

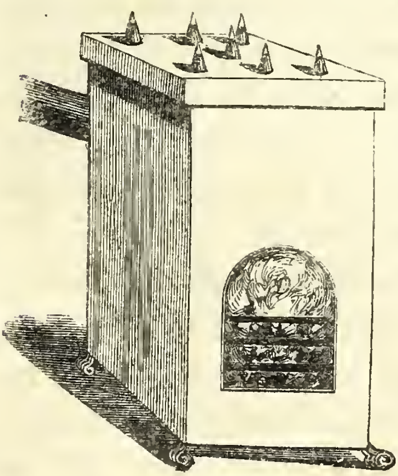
But all bodies, or parts of bodies, which are in immediate contact with some other at a higher temperature, become themselves warmed; *not* by rays thrown out from the heated mass, but by *conducting* or diffusing the heat from one point to another, and so disseminating it ultimately throughout their whole substance.

Humphry was thus particular in impressing upon his mind the precise difference between the *radiation* and *conduction* of caloric before entering upon the study of the latter process; for he knew that without clear and distinct views upon the subject it was impossible for him to arrive at any absolute knowledge.

To illustrate the *gradual* progress of heat by *conduction*, the lad took a square bar of iron, about 20 inches long, and he attached to the under side of it (by means of a little wax) 10 small wooden balls, so that they were about 2 inches apart from each other. Then he heated one end of the bar in the flame of a lamp, and found that the balls fell from under it *one after another*, as the heat found its way along the metal and melted the wax below. The arrangement of this simple and instructive experiment is here shown.



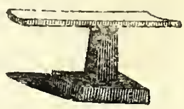
The next step was to learn the different conducting powers of different substances. For this purpose Humphry had several small metal cones made, all of the same size; one of these was of copper, another of iron, a third of zinc, a fourth of tin, a fifth of lead, a sixth of marble, and a seventh of brick. Then having tipped each of them with a small piece of wax, he stood them, all a short distance apart from each other, on the metal plate at the top of the iron stove by which Mr. Borlase's sur-



gery was heated. The result was, that the wax at the top of the *copper* cone was the first to melt. Some little time afterwards, that at the apex of the *iron* began to liquefy; and soon after the iron, that upon the *zinc* was rendered fluid; while, shortly following the zinc, the wax on the *tin* commenced trickling down the sides. A short interval elapsed, and then the cerate at the top of the *lead* became fluid. Again a lapse of a few moments occurred, after which the wax with which the *marble* cone was tipped began to flow; and, last of all, that upon the piece of *brick* was liquefied.

The different conducting powers for heat among the several substances employed were thus made evident. The metals were more capable than either marble or brick of diffusing the caloric from one part of them to another; while among the metallic substances themselves copper was proved to be a much better conductor than iron; iron, again, a little better conductor than zinc; and zinc, too, slightly better than tin. Lead, on the other hand, was the worst metallic conductor of all.

The limited means of the young experimentalist, however (for Humphry was obliged to seek Mr. Tonkin's assistance for any particular apparatus he required), did not admit of his testing the conducting powers of either gold or silver. But had he done so, he would have found that the precious metals were much better conductors than any other —*gold* being the best of all, and *silver* only a little inferior to it. *Platinum*, however, was a striking exception, its heat-conducting power being only a little superior to that of iron.

Humphry after this sought to discover what would be the effect if he placed a good conducting metal in connexion with a bad one. For this purpose he employed a short curved bar of copper; and having heated it, he set it across the top of a small leaden pillar to cool, thus:  when, to his utter astonishment, a series of musical sounds were given forth as the copper cooled, the tones now rising and now falling like those of an Æolian harp.

By the same means as Humphry had employed for testing the conducting powers of the metals, he ascertained that *wood* was a very bad conductor of heat, and that the *lightest* woods were the worst. *Charcoal*, too, he found to have but little power of diffusing the heat from one part of it to another. This explained to the boy the reason why a piece of charcoal, red-hot at one end, may be held—at a short distance even from the heated part—without burning the fingers.

Humphry now set to work to raise to a considerable temperature several pieces of such substances as he had ascertained to be good and bad conductors, so that he might learn what effect they respectively produced upon the touch when highly heated. As he had anticipated, the *bad conductors*—such as the wood and brick—could be handled without pain, whereas the *good conductors*—like the metals—burnt the fingers immediately they were brought into contact with them.

Pursuing this result, the lad, eager to display his knowledge to the servant of the house, took the boiling kettle from the kitchen fire, and, to the amazement of the maid, allowed the sooty bottom of it to rest upon his palm; for the crust of charcoal with which (by long usage) the vessel had become coated underneath—being a non-conductor—prevented the heat of the boiling water within being communicated to the hand.*

On recounting to Mr. Borlase the experiments he had performed concerning the conduction of heat, Humphry was informed by that gentleman that it was painful to touch good conductors like the metals when they were heated about 120°. Air, however, he told the boy, might have its temperature raised even to 300°, without producing any sense of burning; adding, that some eminent sculptors had large ovens in connexion with their studios, for drying the moulds they

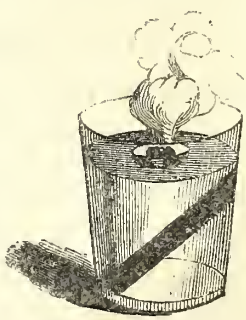
* Young gentlemen of an experimental turn are cautioned against attempting the same feat; for, should there be the least part of the metal, at the bottom of the kettle, left unprotected by the soot, they will assuredly experience considerable pain.

employed in bronze castings; and though these places were often heated far above the boiling point of water, the workmen entered, and remained there for some minutes without much inconvenience; and even persons unused to such high temperatures might walk in and out of the ovens with impunity, though to such any attempt to remain occasioned a difficulty in breathing and a painful sensation about the eyes. It was found necessary, however, under such circumstances, to carefully avoid *the contact of any good conductor;* for if, while in the heated oven, a piece of metal were touched, it would inevitably burn—even the coins in the pocket were sufficient to produce intense pain. "A story is told," he continued, "of a person who once, inadvertently, entered such a place with his spectacles on, and these, being mounted in silver, soon blistered the parts of his face with which they were in contact. On the other hand," proceeded the surgeon, "it has been found that in high northern latitudes, where the cold is sometimes sufficiently intense to freeze mercury—though this requires the temperature to be 72° below that required to freeze water—yet even such excessive cold may be borne without uneasiness, provided the air be tranquil, and the persons well clothed in good non-conductors, such as wool and fur. If, however, *metallic substances* be touched at this low temperature, a sensation like that of burning is experienced, and the part quickly becomes blistered. "The reason of this," the doctor concluded, "is, that the heat, being as it were free to move in all those substances which are, like the metals, good conductors of it, is readily communicated to us by such substances when at a higher temperature than ourselves, while our heat is as readily abstracted by them when they are colder than we are. Hence good conductors, like metals, always feel colder to the touch than bad conductors, like wood or fur—even though these latter bodies can be shown by the thermometer to be of the same temperature as the others."

Humphry's conversation with the doctor induced him to try another experiment, illustrative of the conducting power of wood and metal. He took a small rod of polished brass, about a foot in length, and stretching a strip of writing-paper tightly over it at one end, he tried to burn the paper in the flame of a lamp, but discovered that it was impossible even to scorch it; for the heat, as soon as applied, was *conducted away* so rapidly along the metal, that it prevented the temperature of the paper being raised sufficiently to char it. On substituting, however, a smooth piece of wood for the brass rod, he found that the paper stretched over the end of it soon began to scorch in the flame, and that the wood itself shortly became ignited in consequence of its bad conducting power, which, opposing the diffusion of the heat along it, concentrated the effects upon the spot to which the flame was applied.

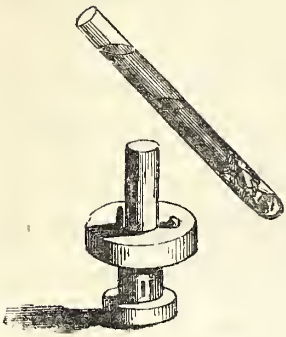
After this, the boy began to turn his attention to the conducting powers of *liquids*, rather than *solids*, with which he had previously dealt.

That liquids are very *imperfect* conductors of heat, Humphry made out in the following manner: He filled a tumbler with water, and in this he placed a piece of "fusible alloy," which is a composition of metals melting at a temperature below boiling heat. Then a thin copper basin was made to float on the surface; and into this he put some pieces of red-hot charcoal; so that, after a time, the stratum of water at the top of the tumbler began to boil; but, even though the upper part of the liquid was at boiling-point, so slight was the power of the water to *conduct* the heat from one part of it to another, that the stick of alloy, which reached within an inch of the top, remained wholly unmelted by it.



The same effect was found to ensue with heated *oil*, though this the lad tried in a somewhat different manner. In a thin glass tube a small quantity of water was frozen by plunging it into a mixture of salt and snow. Then, upon the lump of *ice* at the bottom a small quantity of *oil* was poured;

and, lastly, upon the oil some *spirits of wine* was made to float. The tube was now held over the chimney of a lamp, and the spirit made to boil until the whole was evaporated, when, on plunging a thermometer into the oil, it was found to be but slightly heated, while the ice itself had undergone no change, but remained still solid at the lower part of the tube.

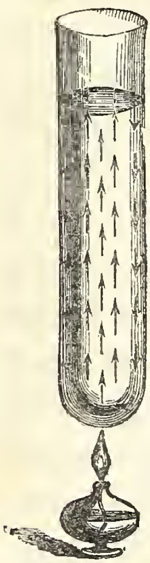


Next, in due order, came the conduction of heat by *gases* and *vapours;* and of this Humphry obtained a remarkable illustration in a fact which he learnt of the engineer at the Wherry Mine, who told the lad that high-pressure steam did not burn, though its temperature was some hundred degrees above that of steam at a low pressure. The scalding effect of the vapour at a low pressure, the man informed the youth, arose from the small particles of hot water that were diffused throughout it, and which, indeed, rendered it visible in the air; whereas in high-pressure steam no such watery particles existed, and the vapour was consequently not only imperceptible to the sight, but, being a bad conductor of heat, it had no more power to burn than so much hot air.

Again, that *gases*, in a state of combustion, are bad conductors of heat, Humphry was aware, from having repeatedly passed his finger through the flame of a spirit-lamp without burning it, and yet the temperature of such a flame might be shown to be many hundred degrees beyond that of a piece of red-hot metal. *Air*, again, he knew to have little or no conducting power; and he had heard from Mr. Tonkin that in Russia and other cold countries double windows, with a stratum of air between them, were used to prevent the heat of the apartment being carried off. So, again, in furnaces, double walls with a stratum of confined air in the middle are employed to stop the *egress* of heat: even as in ice-houses the same means are adopted to stay the *ingress* of it.

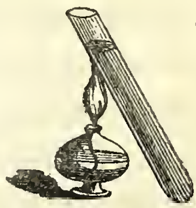
The diffusion of heat by the process of *conduction*, however, generally occurs among *solid* bodies, in which the particles are more or less firmly united; but *liquids* and *gases* (where the particles, owing to the want of cohesion among them, are free to move) mostly became warmed by a very different process; that is to say, the heat applied to them is spread from one part to another—not by being propagated, as in solids, from one fixed particle to that which is next to it—but by the *motion or circulation of the heated particles themselves*, so that each in its turn receives a portion of the heat applied, and then giving place to another particle, the whole mass ultimately becomes raised to one uniform temperature by the *direct* agency of the radiant body, rather than by the *indirect* process of transference from atom to atom along the entire substance. The one process is termed the *conduction* of heat, the other the *convection* of it; and while the former prevails among the *cohering* particles of solid bodies, the latter generally obtains among fluids whose atoms are *free to move*.

In order to render visible this same circulation of the particles of fluids while in a heated state, Humphry bruised in a mortar a small piece of amber, and then having filled a glass tube with water, he threw in a few pinches of the powder, which, being nearly of the same specific gravity as the liquid, neither sank nor floated in it. Then applying a gentle heat to the centre of the bottom of the tube, the boy saw, by means of the amber-dust suspended in the fluid, that currents immediately began to *ascend* in the middle of the water, and to *descend* in it at the sides of the vessel—in the direction of the darts in the above engraving.



If, however, he heated the sides of the tube, the currents were found to take a contrary direction, going *upwards* at the sides and *downwards* in the centre.

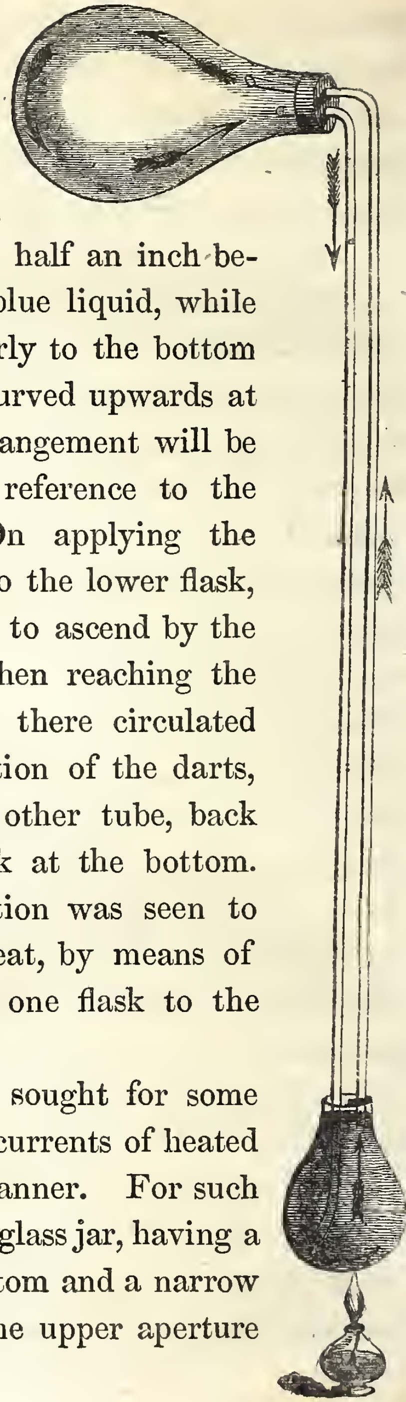
On continuing the heat, Humphry perceived the currents to become more and more rapid, till the water boiled, and when the whole of the liquid had acquired an uniform temperature, he observed that they ceased altogether. He then endeavoured to ascertain if it were possible to produce these currents in a liquid by heating it at the top, but the boy discovered, on applying a spirit-lamp to the upper part of the tube, thus—



that though the top of the water was made to boil, and the amber-dust there thrown into rapid circulation, the particles at the bottom remained unmoved, the fluid below being undisturbed and cold.

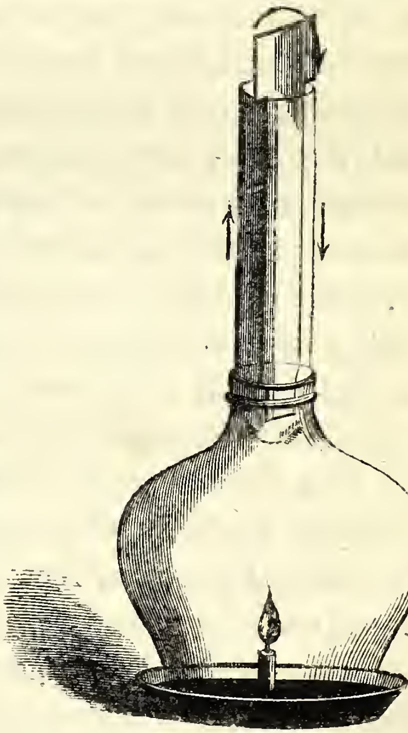
The reason of this was almost self-evident. The warm water was *lighter* than the cold, and therefore *rose* to the top immediately it became heated, while the cooler and *heavier* portions *descended* to occupy its place. Hence, in heating the tube at the bottom the current was observed to go upwards in the middle and downwards at the sides, these being kept comparatively cool by the action of the external air.

Pursuing this subject, Humphry took a large and a small Florence flask, and into the mouth of the large one he fitted two long bent glass tubes, by means of a perforated cork and cement. These, together with the large flask, were filled with water and then made to dip into the open mouth of



the smaller flask, which was likewise filled with water, but tinged a deep blue with indigo. One of the tubes was arranged so as to dip only about half an inch below the surface of the blue liquid, while the other descended nearly to the bottom of it, and was slightly curved upwards at its extremity. The arrangement will be readily understood by reference to the annexed engraving. On applying the flame of a spirit-lamp to the lower flask, the blue liquid was seen to ascend by the tube on the left side; then reaching the large flask at the top, it there circulated through it, in the direction of the darts, and descended by the other tube, back again to the small flask at the bottom. Thus a perfect circulation was seen to be kept up, and the heat, by means of *convection*, carried from one flask to the other.

After this Humphry sought for some means of rendering the currents of heated air visible in the same manner. For such purpose he took a large glass jar, having a wide opening at the bottom and a narrow one at the top. Into the upper aperture he inserted a long lamp-glass, and down this he placed a diaphragm of card, so as to divide the glass chimney into two channels. Then the lad procured a shallow pan, and having poured a little water into it, he set a piece of lighted candle in it and covered it over with the jar and chimney, so that when the whole was duly arranged it appeared as here shown. Then having lighted a piece of brown paper and blown it out again, he held the smouldering end over the chimney, and saw, by the curling of the smoke from the paper, that the heated air from within was *ascending* the lamp-glass by one side of the diaphragm, and *descending* by the other, in the direction of the arrows in the illustration; whereas, when the card-board partition was removed from the chimney, the currents *ceased*, and the light was soon extinguished.



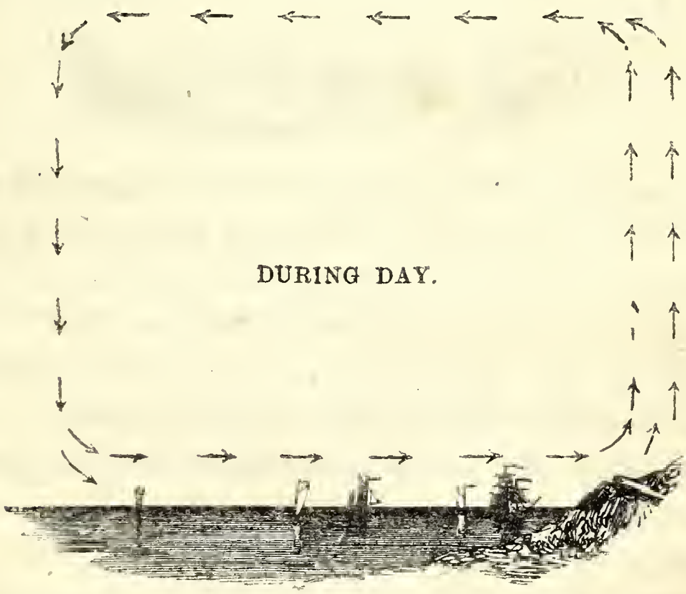
The boy applied the same simple means, likewise, to learn the direction of the currents of air on opening the door of a heated apartment, and found, by the smoke from a piece of smouldering paper, that at the *upper* part of the door the heated air from within was rushing *outwards*, and at the *lower* part the cold air from without was setting *inwards*, whilst at the middle scarcely any draught, one way or the other, was perceptible.

This naturally turned the boy's attention to the subject of the wind, which appeared to him to be merely a vast current set up in the atmosphere by the heating power of the sun's rays. He had noticed, too, that, shortly after sunrise, a breeze frequently sprang up at sea and blew towards the land, increasing as the day advanced, and declining and ultimately expiring at about sunset; whilst in the evening, after sundown, a wind often arose in the opposite direction—namely, *from* the land *towards* the sea—and lasted the whole of the night, ceasing only with the reappearance of the sun.

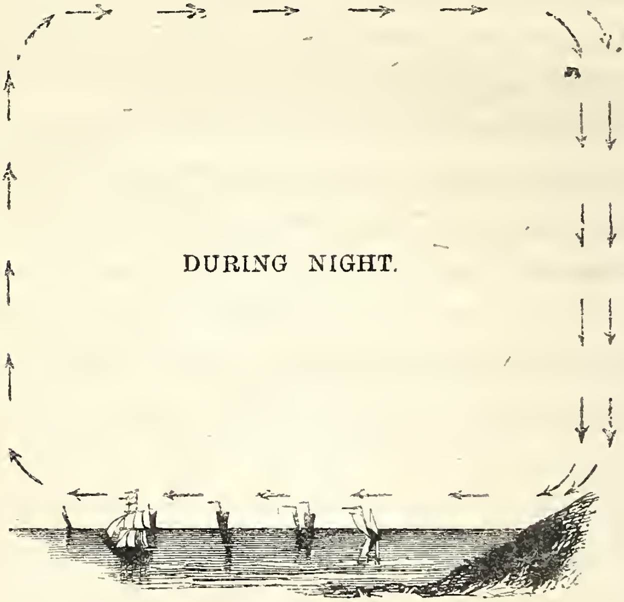
Humphry was therefore anxious to discover some experimental means of reproducing these effects on a small scale.

Having procured a large shallow milk-pan, he filled it with cold water, and then took a metal "hot-water plate," and having poured some boiling water into this, he set it in the middle of the pan, saying to himself as he did so, "the cold water there, in the outer vessel, represents the ocean, while the heated metal plate in the centre stands for an island warmed by the rays of the sun; for the land, being a better absorber of heat than the sea, will have its temperature raised some degrees higher than the water in the course of the day."

This done, the eager boy proceeded, by means of the smoke from a piece of smouldering paper as before, to discover the direction of the currents that would be set up in the air under such circumstances. As he held the smoking paper at the edge of the pan, Humphry was delighted to see the white fumes drawn towards the hot plate in the middle, or, in other words, *from* the miniature ocean *towards* the mimic island encompassed by it; and this he knew was precisely the current that was found to prevail throughout the day in tropical countries.

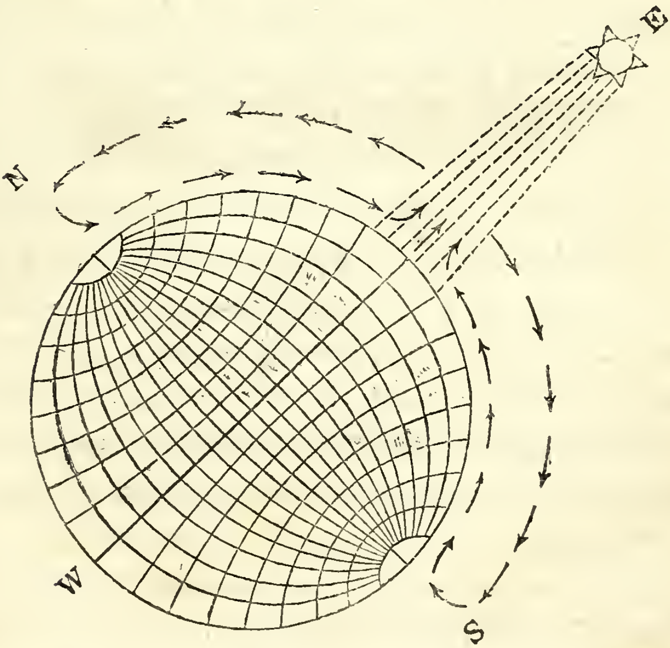


Then, to impress the phenomena firmly upon his mind, the boy drew in his note-book the annexed diagrams, illustrative of the currents produced in the atmosphere by the *heating* of the earth during the *day*, and the *cooling* of it during the *night*. "But if the



inequality of the temperature between the land and the sea gives rise to such results, how much greater," mused the boy to himself, "must be the effect produced by the difference between the heat of the earth at the equator—where the average temperature is said to be 80°—and at the poles, where it is calculated to be as low as 56° below zero, the difference being as much as 136°! What a vast aërial current must be set up by such means!"

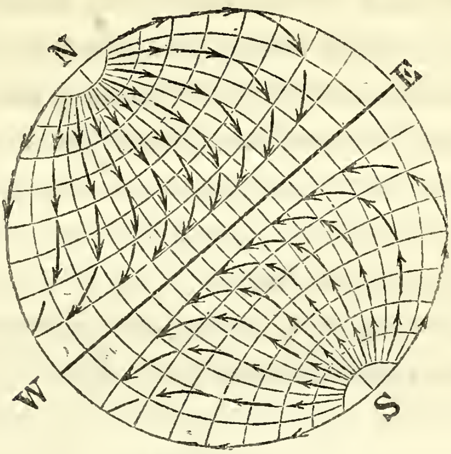
Then the lad made another drawing, illustrative of the effect that would ensue under such conditions, and he set above it a series of arrows to show the direction of the currents that would be thus induced in the atmosphere. For the air, being heated by the vertical sun at the tropics, rises there, as it does up a chimney, while the colder air from the northern and southern hemispheres glides in from below, on both sides of the equator, to supply the place of that which has been made to ascend by the heat; precisely in the same manner as, when the fire burns, fresh air is continually rushing in under the door and windows. Then the heated air, after rising to a considerable height above the earth, at length flows over, as it were, and forms in the



atmosphere an upper current *from* the equator *to* the poles, where it becomes cooled, and is then drawn down to supply the place of that which has been drafted *from* the colder *to* the warmer regions. "But," said the boy, as he surveyed the drawing, "according to this the winds which are found to prevail in the tropics should blow *north* and *south;* whereas they are found to come from the *north-east* and *south-east* quarters."

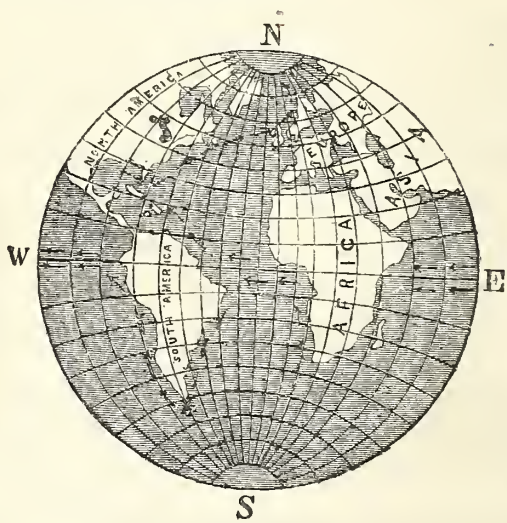
Humphry puzzled himself for a long time in endeavouring to explain the phenomenon, but it was more than his philosophy could accomplish; so he had to consult his old friend Mr. Tonkin again, and from him he learnt that the change in the direction of the currents is due to the motion of the globe and the unequal rates at which different parts of the earth's surface revolve. Consequently, as the currents of air which set in towards the equator from the poles come from parts that revolve about the axis at a much *slower* rate than the equator itself, they *hang back*, or *drag*, upon the surface, in a contrary direction to the rotation of the earth itself; so that, while the globe turns eastward, they acquire somewhat of a westerly course, and, appearing to come from the opposite quarter, assume, therefore, the character of permanent *north-easterly* and *south-easterly* winds.

But to make the matter clearer, Mr. Tonkin exhibited the following illustration to the boy, in which the effect of the earth's motion in changing the direction of the atmospheric currents is immediately apparent.



The old gentleman, however, informed Humphry that there are other terrestrial currents produced by the process of *convection.* In the ocean the same circulation of hot and cold streams is found to obtain; for the sea, warmed by the heated shores of the tropical regions, is made by *convection* to move from the equator like a vast river, while from the poles an immense current of colder liquid streams forward to supply its place. For the same reason as was before explained in connexion with the trade-winds, the polar current, having a slower rate of rotatory motion, assumes, on reaching the equator, a westerly direction, and so flows in one broad stream across the globe; then, striking against the vast continent of America, it divides into two large streams. One of these flows southward down the eastern coast of Southern America, and finally enters the Pacific Ocean through the Straits of Magellan. The other turns northward, enters the Gulf of Mexico, sweeps round the coast in a powerful current known as the Gulf Stream, and then proceeds along the Northern American shores to the coast of Newfoundland, where it crosses the world again, and occasionally extends even to the western shores of the British Isles.

The direction of these oceanic currents is indicated in the subjoined chart:



"There is, however," continued Mr. Tonkin, "another great heat-stream traversing the earth, though this takes place within the crust itself, and is due more to *conduction* than *convection*, as in the other cases. For philosophers tell us, that the daily impressions of heat which the earth receives from the sun, follow each other into the interior of the mass, like the waves which start from the edge of a canal, and, like them, become more and more faint as they flow on, one after another, till they melt into the general level of the internal temperature. The parts of the earth near the equator," added the old man, "are more heated by the sun than other parts, and on this account there is a perpetual internal *conduction* of heat from the equatorial to the northern and southern regions. Then, as all parts of the earth's surface throw off heat into space by radiation, it is plain that at the poles, where the surface receives but little warmth from the sun, a constant waste of caloric is produced. There is thus a perpetual dispersion of heat *from the polar parts* into surrounding space, which is supplied by a perpetual internal flow of heat *from the equator* towards the poles. The radiation from the surface of the earth," Mr. Tonkin concluded, "has its limit in the temperature of the planetary space in which it moves (for we may conceive our globe to be like a heated ball cooling down, *in vacuo*), and this has been calculated to be not more than 56° below zero, —which low temperature, indeed, appears to be attained in the long absence of the sun in a polar winter."

The poetic boy was lost in wonder at the marvellous results to which his investigations had led him, and his mind was filled with a sense of sublimity at the thought of the enormous heat-tides that are continually flowing through the atmosphere, the ocean, and the solid crust of the earth itself.

"I'll work it all out myself," he cried; "that I will. I'll not rest until I know all that is known of Nature and her wondrous ways."

CHAPTER VIII.

THE WONDERFUL EFFECTS OF HEAT.

The effects of heat are manifold.

In the first place, an increase of temperature *expands* or enlarges almost all bodies, while a decrease causes them to *contract* or become diminished in bulk.

Secondly. Heat *changes the form* of bodies, converting solids into liquids, and liquids into vapours; while cold, on the other hand, condenses vapours into liquids, and causes liquids again to solidify or congeal.

Thirdly. Heat causes *ignition;* that is to say, it changes dark opaque substances to a bright transparent red, rendering them capable of giving out light, when their temperatures are raised to a high degree, and, when increased to the highest point, causing them to become even white in the fire, and then endowing them with the properties of the solar beams, so that their rays have the same power of traversing plates of glass, and of producing chemical changes, even as the rays of the sun itself.

Fourthly. *Combustion*, or the burning of bodies, with the evolution of flame, is another effect of heat. There is also a species of combustion called *slow* (*erema-causis* is the chemical term for it), which is unaccompanied with flame—as in the rotting of wood and other organic tissues, the rusting of metals, and even the breathing of animals and ourselves. In each of these processes there is the same combination of a combustible body with the oxygen of the atmosphere—but at a much *slower* rate—than in the more rapid and energetic forms of combustion; and hence but slight increase of temperature (if any) is discernible, while no flames or luminous gases that are perceptible to our senses are evolved under such conditions.

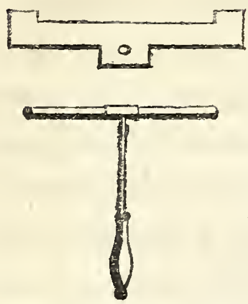
Fifthly. *Phosphorescence* is likewise produced by heat. During combustion and ignition, bodies become *temporarily* luminous; but in states of what is called phosphorescence they are *permanently* so; and there are many substances—such as the compact phosphate of lime, the dark-blue kind of Derbyshire spar, several varieties of heavy spar, and powdered quartz—which acquire the property of shining constantly in the dark after having been made nearly red hot.

Sixthly. *Electricity* is induced by heat; for it has been discovered that if a bar of the metal called antimony be heated at one end, while the other is kept cool, an electric current ensues.

Lastly. Heat promotes both *vegetable* and *animal life.* For not only is intense cold destructive of organic existence, but the increased warmth of the summer invariably calls into being an infinite number of plants, flowers, insects, and the many forms of organised nature that give variety and grace to the earth. Moreover, heat produces in ourselves, and other sentient animals, a *feeling of warmth*, and the absence of it a sensation of cold; by which we are enabled to measure—though hardly with perfect accuracy—the different changes of temperature occurring in the substances around us, and also, by the agreeable impression which we derive from warmth, induced to seek that degree of heat which is best fitted for the promotion of our health and development of our faculties.

Humphry began by studying the laws which regulate the expansion of bodies under the three different forms in which they exist in nature, viz. *solids, liquids, and gases or vapours.* To determine the expansion of different solids, the youth procured short bars of the several substances upon which he had decided to experiment. The bars were all of the same length and thickness, and were accompanied with a gauge, which measured their dimensions at ordinary temperatures.

The following diagram illustrates the apparatus



employed. The first step was to test the length and breadth of each bar that was to be used. This was performed first, by placing it in the gap at the upper part of the gauge, and seeing whether it exactly fitted between the notches; and secondly, ascertaining whether it was precisely of the same diameter as the hole at the bottom part of the plate. This done, the bars were successively plunged into hot water, when, on applying them once more to the gauge, they were found to be so much *enlarged* in all their dimensions that it was impossible to make them pass through either of the apertures. After this they were severally cooled down, by immersion in a mixture of snow and salt, to the temperature of the freezing-point of water, when they were discovered to have considerably *contracted* in bulk; so that they could be passed through both of the openings with perfect ease.

It was by such means Humphry ascertained that different solids possessed different degrees of expansibility, and that metals are more susceptible of change of bulk than other solid bodies. Each solid, however, was found to have a rate of dilatation peculiar to itself. *Lead*, for instance, when heated, from the freezing to the boiling-point of water, was discovered by measurement to have expanded one-350th; *iron*, one-800th; and *glass*, one-1000th.

Platinum, however, was found to be less expansible than iron, and *copper* more so. *Silver*, on the other hand, was more expansible than copper, while *tin* was more so than silver; *lead*, again, more than tin, and *zinc* even more than lead: so that glass was proved to be less capable of being increased in bulk by heat than the metals; whilst, among the metals themselves, platinum was ascertained to be the least expansible, and zinc the most so.

On talking over these matters with Mr. Borlase, the doctor told Humphry that the expansion of metals was a matter of considerable importance in many arts. "For instance," said the gentleman, "coopers put the iron hoops upon their casks in a heated state, so that they may gradually contract on cooling, and firmly bind the staves together. With the same view the wheelwright heats the tire of his wheel, in order that it may, as it cools, press strongly upon the 'felly,' or circumference; and, for the same reason, the plates of large boilers are united with red-hot rivets, which, during their contraction on cooling, draw the sheets of metal closely and securely together.

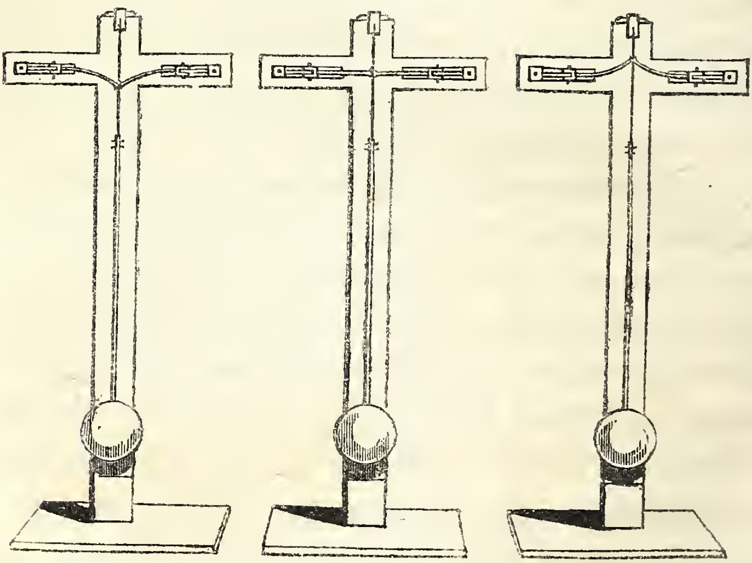
"In the iron bridge," continued the doctor, "which was constructed over the Severn in Shropshire, when I was a lad, it has been found that the arches are nearly one inch longer in summer than they are in winter; so that, if due allowance had not been made for the expansion of the metal, the stone piers, on which the arches rest, must have given way to the pressure long before this. The same allowance for expansion, Humphry, has to be made in the clamping together of stones in the construction of church steeples; for the changes of bulk which occur in metals at different temperatures, though comparatively small in amount, take place with irresistible force."

The perpendicularity of the walls of the Museum of Arts and Manufactures, in Paris, it may be added, were restored by Molard, upon the same principle. In consequence of the weight of the roof, the walls were bulging outward, and, in order to straighten them, iron rods were laid across the interior of the building, their ends being made to project through the brickwork outside. These rods were then heated, and, when in an expanded state, a strong iron plate was passed over each end of them, and screwed firmly up against the exterior of the walls. As the rods cooled, they naturally contracted, and drew the walls somewhat nearer together. The bars were afterwards again elongated by heat, and again screwed up previous to their contraction; and so, by a repetition of the process, the walls were gradually brought to a perpendicular position.

Humphry was delighted with the ingenious applications of the expansion and contraction of metals by heat and cold, and Mr. Borlase, observing the interest he took in the subject, proceeded to explain to him how, by the same principle, the alterations in the length of the pendulum of a clock were "compensated," and the instrument so made to vibrate seconds at all seasons. For a pendulum to beat exactly sixty times a minute, he told the boy, it was necessary that it should be a fraction more than 39 inches long, in the latitude of London. "If, however, the pendulum be made of metal," he said, "it will be liable to be *longer* in summer and *shorter* in winter; so that the clock will be slow in the warm weather season and fast in the cold: for when the bob is let down the one-100th part of an inch the clock loses 10 seconds in 24 hours, and a change of temperature equal to 30° (which is nearly the difference between summer and winter, in our climate), will alter the length of the pendulum-rod about one-5000th part, and so occasion an error in the rate of going of 8 seconds a day.

"To counteract the expansions of the metal rod of the pendulum," continued his preceptor, "there are many ingenious contrivances. The simplest of these, perhaps, is as follows: A compound bar of two differently expansive metals, such as steel and brass, is formed by rivetting or soldering the two metals together; for if such a bar, with the brass *uppermost*, be placed upon a heated plate, it will be found to warp or curve *downwards*, in consequence of the expansion of the brass being greater than that of the steel. If, however, on the other hand, the compound bar be placed on a plate cooled down by a mixture of snow and salt, it will be found to warp or curve *upwards*, because the brass will contract the more with the cold. Now, if two such compound bars, with the most expansible metal at top, be placed at the upper part of a pendulum-rod, one on either side of it, and firmly fixed at one end, they will, as they warp upwards or downwards, tend to shorten the pendulum-rod when it becomes lengthened by the heat, and to lengthen it when it becomes contracted by the cold.

To make this more readily intelligible to Humphry, the doctor exhibited to him the following engravings:



"Let us now," said Mr. Borlase, as he placed his finger on the centre drawing, "suppose the pendulum, with the compensation-bars perfectly horizontal, to be vibrating seconds at a temperature of 60°, and that, some few months afterwards, the heat rises to 80°; in such a case, of course, the pendulum-rod would be *elongated by the heat*, and the longer the rod the slower the vibrations, so that it would then vibrate *less* than sixty times in the minute. The effect of the increase of temperature, however, on the compensation-bars (the most expansible metal being uppermost), would be to warp them *downwards* (as shown in the left-hand drawing)," said the doctor, pointing to the illustration, "and thus they would *shorten* the pendulum-rod as much as the heat had lengthened it. In cold weather, however, Humphry, the metal rod of the pendulum would be *diminished in length;* but then the compensation-bars would warp *upwards*, and so tend to *elongate* it, to the same extent as it had been contracted by the cold (as may be seen on reference to the picture on the right hand)."

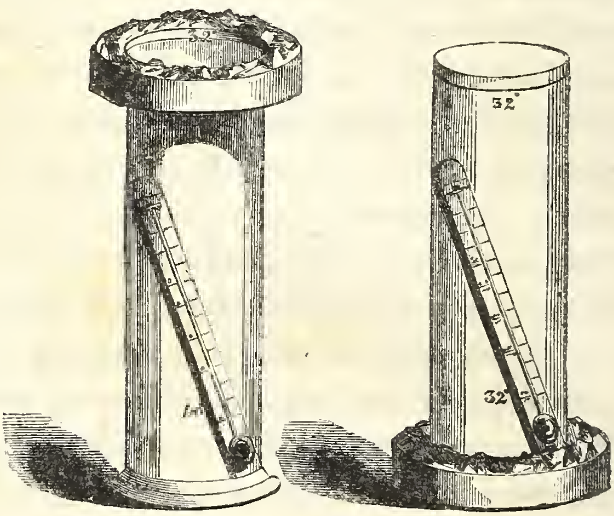
The next day Humphry was busy making experiments concerning the expansion of *liquids*. He first took a large thermometer tube and poured into it a sufficient quantity of spirits of wine to fill the bulb at the bottom and make the fluid rise some few inches in the stem above. Then, having marked upon the glass with a file the level at which the spirit stood at an ordinary temperature, the boy plunged the instrument into a vessel of boiling water, and immediately beheld the liquid rise in the tube till it stood several inches above its former level. After this he immersed the tube in a mixture of snow and salt, and found the liquid contract, so that it fell in the stem almost down to the bulb. On removing the instrument, however, the fluid immediately commenced rising again, and so pleased was the youth with the motions that he repeated the experiment over and over again, being not a little delighted to perceive that each time, as he plunged the instrument into the hot or cold bath, the spirit invariably rose or fell to precisely the same place in the tube.

To measure the different rates of expansion among different liquids, the young chemist provided himself with a long and narrow glass tube, which was graduated into cubic inches, and into this he poured a certain quantity of the liquid he wished to experiment upon. Then plunging the graduated tube into the snow-and-salt mixture, he noted the precise volume of the fluid at that temperature; after which he immersed it in a vessel of boiling water, and then noted again how many cubic inches it occupied in the tube at the higher temperature; so that the difference told him how much the liquid had been expanded between 32° and 212°, or the freezing and boiling point of water.

It was thus the lad ascertained that 9 measures of spirits of wine at 32° become expanded into 10 measures at 212°, and 9 measures of strong aquafortis also become 10, between the same extremes of temperature. Again, 12 measures of olive oil are increased into 13, while 14 of ether and the same quantity of oil of turpentine swell each into 15, with the like increase of heat. Then 17 measures of oil of vitriol, at the freezing-point of water, are dilated into 18 at the boiling-point, and $22\frac{3}{4}$ measures of water are increased to $23\frac{3}{4}$ within the same range of temperature, while $55\frac{1}{2}$ of quicksilver become $56\frac{1}{2}$ when similarly treated; consequently spirits of wine is no less than 6 times more expansible than quicksilver, so that in the depth of winter 100 pints of spirits of wine are dilated into 105 in the height of summer.

While making his experiments, however, as to the rate of expansion in liquids, the boy had been astonished to perceive, when the tube contained water, that, on placing it in the mixture of snow and salt, the liquid, as it was cooled down, continued to shrink till it had attained the temperature of about 40°; and then, *instead of contracting any farther* (as was the case with other liquids till they froze), *it began to expand slowly, and kept rising in the tube until it congealed.* He noticed, too, that, when the water was at its freezing point, or 32°, it was of the same bulk as it was at 48°; so that it expanded just as much for the 8° below 40° as it had contracted in the 8° above that point.

Humphry then tried another experiment illustrative of this remarkable property of water. Having produced two cylindrical glass vessels, he surrounded one of them at the bottom with a circular tin tray, that fitted closely to the exterior of the cylinder, and affixed to the other a similar tray, but this he placed at the upper, instead of the lower part of the cylinder as before—in the manner represented in the subjoined engraving:



A thermometer then having been placed in each of the glass vessels, they were respectively filled with water at 50°, while a freezing mixture of pounded ice and salt was placed in each of the trays.

After the temperature of the whole of the water in both vessels had been reduced to 40°, it was found by the thermometer in the vessel, with the freezing mixture *at the top*, that the cooling effect would not proceed downwards, *but was limited to the surface*, where the water ultimately froze; for the ice-cold water being *lighter* than the water below at 40°, necessarily *floated* like oil upon the surface. In the other cylinder, however, where the cold was applied at the *lower* rather than the upper part of the water, the effect was very different; for there, the liquid becoming lighter, as its temperature sank below 40°, *ascended*, whilst the warmer and heavier water at the top *descended*, until it was cooled, and so expanded in its turn; and thus the *whole* of the liquid was ultimately reduced to the freezing-point; whereas in the other cylinder this effect was limited to the *surface* only. Humphry now could see the reason why lakes and ponds froze only on the surface, and why, on breaking the ice (as he had repeatedly done when out snipe-shooting with his uncle, Leonard Millett), the water underneath was always found to be warmer than the air above.

The lad had now but to investigate the rate of expansion among *aëriform bodies*, or *gases*, to complete this part of the subject.

Accordingly, he took the thermometer tube he had before used, and placed it, with its open end, downwards, in a glass of water, thus:

The tube was of course filled with air, so he applied his palm to the bulb, and found the heat of the hand sufficient to expand the air within, and drive a stream of bubbles up through the water. On removing the source of heat, however, the volume of air began to contract, and the liquid to mount in the tube, so that he could see by the height the water rose in the stem the amount of expansion which the air had undergone.

Humphry then proceeded to ascertain the amount of expansion produced in a given quantity of air, when heated from the freezing to the boiling point of water, and discovered that 100 cubic inches of air at 32° become dilated to 137½ cubic inches at 212°. Air, therefore, at the freezing-point, expands one-480th for every degree of heat that is added to it; so that 480 cubic inches at 32° become 481 at 33°, and 482 at 34°, and so on, the volume expanding one cubic inch with each additional degree of heat. A volume of air, therefore, at 32° would be doubled at 480°, and tripled at 960°, the latter temperature being that of a dull-red heat.

Steam, and other vapours, when heated by themselves, are subject to the same law of expansion as air.

But although the expansion produced in aëriform bodies by heat is great in amount, the actual force which is thus developed is small when compared with that of solids and liquids under the same circumstances. This is owing to the extreme elasticity of aëriform bodies; so that, although air becomes tripled in volume at a red heat, vessels are easily found capable of sustaining the pressure of the expanded fluid. It is only when a portion of liquid is present, so that *volume after volume* of vapour is added to those already generated—as in the production of steam—that, on resisting the expansion, the pressure becomes enormous, and mounts up to a dangerous point.

CHAPTER IX.

THE WONDERFUL EFFECTS OF HEAT—(*continued*).

"But heat," said Humphry to himself, as he reviewed his previous experiments, "not only *expands* the bulk of different bodies, but it *changes their form*, rendering certain solids liquid, and converting liquids into vapours. Let us see now what occurs during such changes."

Accordingly, the youth proceeded to pound some ice, and to cool it down in a tumbler by means of a freezing mixture to the temperature of zero. The tumbler was then inserted in a bath of tepid water, the temperature of which was maintained, by an argand-lamp beneath it, constantly at 60°. A thermometer having been plunged in the ice, the quicksilver was observed to mount rapidly in the tube until it reached 32°, when the ice began to liquefy. But, though another thermometer in the water-bath showed that the liquid there was still 60° hot—the same temperature, indeed, as when the ice was first immersed in it—nevertheless the thermometer in the tumbler remained *stationary* at 32°—the freezing-point. Nor did it begin to rise until the whole of the ice was melted; after which it mounted gradually, and ultimately settled at 60°, the temperature of the surrounding water.

Humphry was astonished at the effect. "Why did the thermometer," he asked himself, "remain fixed at the freezing-point until the whole of the ice was melted? The heat from the surrounding water must have been entering the ice as much when it began to dissolve, as it did before the thawing occurred, or even afterwards. How, then, came it that the thermometer was not affected by it?"

The eager boy was so puzzled with the mystery, that he could not rest till he had tested the result by another experiment.

Having procured two small glass globes, he filled them both with the same quantity of water. The liquid in one he froze, and that in the other he cooled down to 33°, so that it might be as near as possible to the temperature of the first, without being solid. When the ice in the one globe had just begun to melt, and the thermometer in that vessel marked 32°, the two globes were plunged into a water-bath, the temperature of which was kept at 47° throughout the experiment.

The vessels, therefore, were, as near as possible, under similar conditions of temperature, within and without, and with similar contents—except that the one contained *ice*, and the other *water*.

The progress of the heating was then noted.

In the globe which contained the *water*, Humphry found the thermometer rose in half an hour to 40°. In the globe, however, which contained the *ice*, no less than 10½ hours elapsed before the whole was melted, and the temperature of the resulting liquid raised to 40°, like the other; so that the rate of heating in the ice-vessel was 21 times slower than in that which held the water.

"How can this be?" mused the boy-philosopher. "The actual amount of heat received by the two must have been uniform during the whole time, and yet the ice took 10½ hours to have its temperature raised to 40°, while the ice-cold water needed only ½ an hour to acquire the same heat. How extraordinary!" he inwardly exclaimed; "what can be the cause of it? For," said the lad, as he jotted the figures down in his note-book, "the water in the globe had its temperature raised 7° in half an hour, consequently that must have been the rate at which the warmer liquid in the external bath was giving out its heat to the two globes. Accordingly, in 10½ hours it must have given 10½ times 7°, or 147° in all, to the one containing the ice. Consequently the *ice* required 140 more degrees of heat to raise its temperature to 40° than the *water* did."

Humphry still doubted the accuracy of his conclusions; for they were so marvellous and unexpected by him, that he sat for a long time considering by what experiment he could bring the matter to a positive test. "If," he inwardly exclaimed, "the ice really received 140° more heat than the water, what became of them? The two were each, in the end, of the same temperature; and the thermometer didn't show, nor could I feel, that the one had imbibed more heat than the other."

Presently the boy started to his feet, for a sudden thought had struck him. He would take 12 oz. of pounded ice, and upon this he would pour the same weight of hot water, at a temperature of 172°; so that the difference between the heat of the ice and that of the water would be 172°—32°, or exactly 140°, and this was precisely the quantity of heat that the ice in the previous experiment had received over and above the water.

Humphry wondered again and again, as he prepared the experiment, what the result would be; and when he mixed the warm water with the ice, he was overjoyed to find that the temperature produced was only 32°—the same as that of the pounded ice itself. Hence it was plain the water had lost exactly 140° of its heat, and, moreover, that these had *entirely disappeared*, since the temperature of the colder substance remained the same as at the outset of the experiment.

Then came the question—What had become of the lost heat? Where had it gone? What effect had it produced?

There was but one answer! and this Humphry was not long in divining. The heat which had disappeared had *combined* with the ice, and its effect had been, not to raise its *sensible* temperature, but simply to convert the solid body into a liquid one, so that the caloric had become *latent*, or imperceptible to the senses, as well as incapable of being detected by the most delicate thermometer.

"So, then," cried the boy, as the new thought flashed upon him, "a *liquid is merely a solid, whose particles are kept asunder by so much heat, which is insensible to us.* In this piece of wax the particles are held together by a certain force, which is called the 'attraction of cohesion,' so that when I press upon it I am incapable of separating one part of it from another. If, however, I apply but a little heat to the substance, the cohesion is soon destroyed, and the particles, instead of then firmly adhering one to another, become free to move, and are, consequently, easily separable; so that a rod can be plunged into it when liquefied, and moved about in it with little or no difficulty."

"Yes," he repeated, "a liquid is merely a solid, whose particles are kept asunder by heat."

Humphry was so pleased with the result he had arrived at, that he varied the experiment in a number of different forms.

First, he took some spermaceti (a substance which melts at 112°), and found that a thermometer plunged in this (as in the ice) remained stationary at the melting-point until the whole was liquefied, and that it was not till then that the temperature could be raised above the point of liquefaction.

Next he tried the same experiment with some lead, and found that, though he heated a ladle-full nearly red hot, the temperature of the whole was immediately cooled down again to the fusing-point by the addition of a piece of the solid metal.

Hence the law was manifest, *that in all cases of liquefaction a certain quantity of heat, not indicated by the thermometer, is absorbed, or disappears—this heat being withdrawn from surrounding bodies, and so leaving them comparatively cold.*

Accordingly, now that Humphry had ascertained that liquefaction itself was a source of cold, he proceeded to try what degree of cold he could produce by causing certain substances to melt rapidly.

For this purpose he took some snow and sprinkled a little salt over it, when he observed that the two solids immediately formed a liquid; and then, plunging a thermometer into the mixture, he beheld the quicksilver sink and sink, until it had nearly reached zero, so that it fell from 32° to 0°. Then the boy made a mixture of 5 parts of smelling salts, 5 parts saltpetre, and 16 parts water, and plunging the thermometer into this, he found that it sank from 50° (the temperature of the room in which the experiment was made) to 10° (which is several degrees below freezing-point). With a mixture, consisting of equal parts of saltpetre, ammonia, and water, the thermometer fell 6° lower than in the previous experiment—or from 50° to 4°. Again, with 5 parts of Glauber's salts and 4 parts of oil of vitriol and water, the temperature sank 1° lower still—or from 50° to 3°. Further, having finely powdered some of the crystals of the last-mentioned salt, he drenched them with muriatic acid, when the salt dissolved to a greater extent than it had previously done in the water, and the consequence was that the temperature fell even lower than before—or from 50° to 0°, while the vessel in which the mixture was made became covered with hoar frost; and when some water in a tube was plunged into the liquefied salt, it was speedily converted into a mass of ice.

Humphry was now anxious to see whether the heat which is absorbed, and becomes latent or insensible during the liquefaction of bodies, really *remains* in the liquid, and whether it is given out again or emitted during their solidification.

To satisfy himself upon this point he prepared two vessels, one full of water and the other full of brine, the temperatures of the liquids in each being, at first, precisely 52°. On a very cold day, when the thermometer stood at 22° (*i. e.* 10° below freezing-point), the boy exposed the fluids in these two vessels, with thermometers in each, to the open air, and found that they both gradually parted with their heat to the surrounding atmosphere, and were soon cooled down to 32°; then the water began to freeze very slowly, and during this the thermometer in the water-vessel remained perfectly stationary. The brine, however (which does not congeal till its temperature sinks to 4°), continued to cool on, the thermometer in it sinking without interruption, until it gradually reached the temperature of the external air, or 22°.

Now it was plain that both liquids, in cooling, were alike parting with their heat to the colder air. Why, then, should one and not the other *suddenly cease giving out caloric*, and refuse for a certain time to be cooled down to the same level as the atmosphere around it?

The only explanation of the problem was, that the water, during the process of freezing, was parting with the 140° of heat which Humphry had before seen were necessary to retain it in a liquid form, and that it was the evolution of this amount of caloric which served to keep the temperature of the water for a considerable time at 32°—notwithstanding the cooling effect of the surrounding atmosphere.

Still this experiment hardly satisfied the boy. He wanted to have some *sensible* proof of the evolution of heat from water during the act of freezing. It was true, there was no way of accounting for the fact of the thermometer remaining stationary in one vessel while it was continually sinking in the other, except by supposing that the latent *insensible* heat was being given off from the water as it passed into the solid form. Humphry desired, however, to *see*, as it were, the heat so given off—that is to say, he wished to behold the thermometer *rise* instead of merely *remaining fixed at one point.*

Accordingly it struck the lad, that if he was to keep some water in a vessel perfectly still, and to prevent even the air from agitating its surface, he might be able to cool it down some few degrees below the freezing-point, and then he should be able to see if, in the act of freezing afterwards, the thermometer would really rise as the water solidified. So successfully did Humphry perform this experiment, that he was enabled, by great care, to cool some water in a vessel down to 22° without freezing it. Then he felt a thrill dart through his frame as he agitated the water, and beheld it immediately shoot into a thousand transparent crystals—whereupon the thermometer in the vessel instantly began to rise, and soon stood at 32°, thus showing that the water had acquired 10° of heat almost in an instant.

Whence came this heat, then?

But one answer was possible. It was manifest that the water, in the act of solidifying, *gave out* heat, even as in the act of liquefying ice *absorbed* it.

"But do all things," said Humphry to himself, "give off heat as they pass from a liquid to a solid form? And is solidification, therefore, a *heating* process to surrounding bodies, in the same manner as liquefaction (from the absorption of heat at such times) is a *cooling* one?"

The youth had heard that, if a strong solution of Glauber's salts be poured, while hot, into a flask, and corked tightly down, it will remain liquid when cold, and that on removing the cork it will immediately shoot into a fibrous mass of crystals. He wished to see, therefore, whether, in the act of solidification, heat is evolved from such a solution.

Humphry was not long in preparing the requisites for the experiment, and was then delighted to find, as he watched the crystals, immediately that he withdrew the cork, dart from the surface downwards, the temperature of the substance became so much increased, that the bottle which contained it grew sensibly warm in his hand, though it was perfectly cold before.

Now the lad knew, that in making the solution he had added 2 ounces of water to 3 ounces of the salts, and as the whole of this became solidified on opening the bottle, it was clear that the elevation of temperature arose principally from the *solidification of the water* in the crystalline mass.

Next Humphry added a saturated solution of tartaric acid to some strong liquid ammonia, and found, immediately that the two fluids were poured together, a solid substance was thrown down, and considerable heat evolved.

Again, the lad was aware that, on mixing powdered plaster of Paris with water, there is a like increase of temperature at the moment of the composition "setting;" or, in other words, when the water with which the plaster has been mixed passes into the *solid* form.

Further, he could now perceive that the great increase of heat which occurs during the slacking of lime is due merely to the same cause, viz. the *solidification of the water poured upon it.* Consequently it was plain that water, in passing from the *liquid* to the *solid* form, invariably *evolves* the heat which is necessary to retain it in a liquid state, and which as it passes, on the other hand, from the *solid* to the *liquid* state, it as invariably *absorbs.*

Not only, however, is there an increase of temperature when water becomes solid, but Humphry found the same result to ensue, even when the same liquid is *condensed.* On mixing 4 parts of strong oil of vitriol with 1 part of water, cooled down to the freezing-point, he perceived that the two together occupied considerably less space than they did alone, and that the mixture rose rapidly from 32° to 212°, or from the freezing to the boiling point. The same result ensued when 1 part of snow was substituted for the 1 part cold water; but, strange to say, when the proportions were reversed, so that there were 4 parts of snow to 1 part of oil of vitriol, *intense cold* instead of intense heat was produced—the *increase* of temperature in the one case arising from the *condensation* of the water from the snow, and the *decrease* of temperature, on the other hand, being due to the *liquefaction* of the snow itself.

Moreover, the boy was aware that a piece of soft iron, when hammered, becomes intensely heated; and he had heard that when a bar of red-hot iron is passed through a rolling-mill, its temperature is so much raised that it is rendered nearly white-hot by the extreme pressure, and the consequent condensation of the particles.

Sudden expansion, on the other hand, Humphry found to be a cooling process; and this is one of the reasons why high-pressure steam, on issuing from a small aperture, instead of scalding the hand as ordinary steam would, scarcely feels warm, even though its temperature be some hundred degrees higher than the vapour at a low pressure; for as the compressed steam escapes into the atmosphere, its instantaneous expansion so far cools it, that it is deprived of all power of burning.

Moreover, at the fountain of Hiero, in Hungary, a part of the machinery for working the mines consists of a column of water 260 feet high, which presses upon a large volume of air, enclosed in a tight reservoir, so that the air within is greatly condensed by the enormous weight of the water; and that when a pipe communicating with this reservoir is suddenly opened, the condensed air rushes out with extreme velocity, and then instantly expanding, absorbs so much heat as to precipitate the moisture it contains in a shower of snow — a hat held in the blast being immediately covered with it. So strong, however, is the current of condensed air, that the workman who holds the hat is obliged to lean his back against the wall to retain it in its position.

Another illustration of the cooling effect produced by the sudden expansion of condensed air is afforded in the fact, that if the blast from an air-gun be directed upon a delicate thermometer, the temperature will be found to be lowered at the moment of the discharge.

As yet Humphry had dealt only with the effects produced by the conversion of solids into liquids, or liquids into solids, and there still remained for him to learn what results ensued when *liquids were changed into vapours, or vapours into liquids.*

Accordingly he proceeded to heat some water in an open vessel, and found, as the temperature gradually rose, that the vapour continued to form on its surface till the thermometer reached 212°, when the liquid became violently agitated. But then, although the fire was kept up beneath the vessel as strong as at first, and *the heat continued to flow into it as before*, the quicksilver in the thermometer became stationary, and remained so until the whole of the liquid had been dissipated in the form of steam.

Here, then, was another instance of the absorption of heat during a change of form; and it was evident, that as water required a certain amount of temperature in order to convert it from a *solid* into a *liquid* state, so did it need a proportionate supply of heat to change it from a *liquid* into a *vapour*.

"The heat absorbed during the boiling passed off, perhaps, in the steam," thought Humphry.

On testing the temperature of the vapour, however, it was found to be no hotter than that of the water during its ebullition.

What, then, had become of the heat which had been added since the boiling commenced?

Why, it had been rendered *latent* or *insensible*, being necessary for retaining the liquid in a more rarified form; for as a liquid is but a solid whose particles have been separated, and so made free to move, by the latent heat existing between them, so a vapour is merely a liquid, whose atoms have been driven farther asunder, and made still more easily separable, by the heat imbibed during the process of vaporization. It was evident, therefore, that the production of vapour is attended with a loss of sensible heat, and that, as in the case of liquefaction, heat *disappears* in order to constitute the liquid, so in the case of evaporation a considerable quantity of heat becomes *latent* in the vapour.

To render this part of the subject still more clear, Humphry filled a flat-bottomed tin vessel with a definite quantity of water, at the temperature of 50°. Then, having placed the vessel upon a heated plate, he found that in 4 minutes it had acquired a temperature of 212°, and began to boil, whilst in 20 minutes the whole had evaporated, having been dissipated in the form of steam. The water, therefore, had received $212° - 50°$, or 162° of heat in 4 minutes, which is at the rate of $40\frac{1}{2}°$ in each minute. The heat, however, continued to flow into the water at the same rate during the whole 20 minutes, so that the entire amount of heat received must have been $40\frac{1}{2}° \times 20$, or 810°, and this had become *latent* in the steam. Consequently the total quantity of heat required to evaporate boiling water would be sufficient to raise the water—provided it remained all the time in the liquid state, instead of being converted into steam—as much as 810° above the boiling-point, or altogether to 1022°.

To verify this conclusion, Humphry heated some water under pressure in a "Papin's digester," so that the liquid was prevented evaporating, and raised the temperature of it to 400°. Then the lad opened the valve, and part of the water suddenly rushed out in the form of steam, when the temperature of that remaining in the digester *sank immediately to* 212°. Consequently 188° (400°—212°) of heat had suddenly disappeared, having been carried off by the steam. It was afterwards found that only $\frac{1}{5}$th of the water had gone off in vapour, so that this vapour must have contained not only its own 188°, but the 188° lost by the 4 other parts remaining in the digester; that is to say, the steam must have contained 188° × 5, or 940° of heat altogether. This experiment therefore showed, that steam is water *combined* with nearly 1000° of heat; and in the same manner as the water had been previously observed to *give out* its heat of liquidity, and to make the thermometer *rise* at the moment of its conversion into *ice*, so was it now seen to *absorb* a considerable amount of heat, and to make the thermometer *fall* at the moment of its conversion into *vapour*.

Evaporation, therefore, should be a means of producing cold, in the same manner as liquefaction had been previously proved to be; for if it be necessary, in order to convert liquids into vapours, that a certain amount of heat be absorbed, it is plain that such heat must be drawn from surrounding substances, and thus the vaporization of one body will be a cooling process to others near it.

To test this, Humphry spread out a wet cloth in a keen wind when the atmosphere was a few degrees above the freezing-point, and found that the particles of water, as they passed into the form of vapour,* carried off so much heat from the liquid in the cloth (in the same manner as the steam did in the Papin's digester) that the remainder became frozen, while the cloth itself was rendered hard and stiff by the formation of ice in its pores.

Humphry, however, knew that *ether* was much more vaporisable than water at ordinary temperatures. Accordingly he availed himself of this substance in the production of cold by spontaneous evaporation.

First, he folded a strip of cambric round the bulb of a small thermometer, and allowed some ether to dribble over it, while he increased the evaporation by projecting a current of air upon it by means of a bellows. The quicksilver was immediately seen to fall several degrees below the freezing-point, and on substituting a thin glass tube

* Evaporation goes on more or less rapidly at all temperatures.

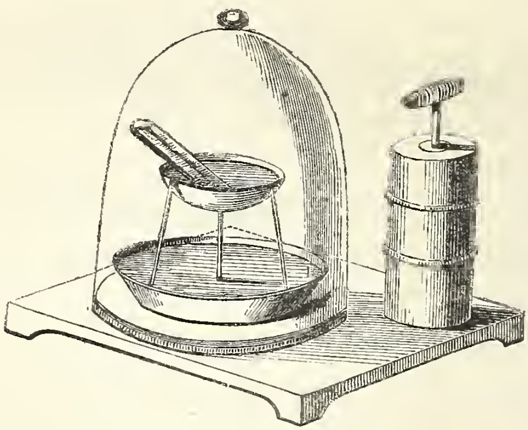
containing a small quantity of water for the thermometer previously used, the boy was enabled to produce ice by the same means.

Next, the lad made use of the air-pump which he had previously constructed out of the rudest materials,* in order to facilitate the spontaneous evaporation of water, by removing the pressure of the atmosphere from the surface of it.

Upon the plate of the apparatus he placed a soup-plate, and this he half filled with oil of vitriol; above the soup-plate he stood a tin basin, supported on three pieces of tobacco-pipe, and three parts filled

* Dr. Paris, in his "Life of Davy" (p. 37), relates the following anecdote concerning the construction of this apparatus: "A French vessel having been wrecked off the Land's End, the surgeon escaped, and found his way to Penzance. Accident brought him acquainted with Humphry Davy, who showed him many civilities, and in return received, as a present from the surgeon, a case of instruments which had been saved from the ship. The contents were eagerly turned out and examined by the young chemist; not, however, with any professional view as to their utility, but in order to ascertain how far they might be convertible to experimental purposes. The old-fashioned and clumsy glyster apparatus was viewed with exultation, and seized in triumph. What reverses may not be suddenly effected by a simple accident! So says the moralist. Reader, behold an illustration: in the brief space of an hour did this long-neglected and unobtrusive machine, emerging from its obscurity and insignificance, figure away in all the pomp of a complicated piece of pneumatic apparatus. Nor did its fortunes end here; it was destined for greater things; and we shall hereafter learn that it actually performed the duties of an air-pump in an original experiment on the nature and sources of heat." It is but right to add, that Dr. Davy doubts the truth of the above story.

with water, in which a small thermometer was immersed; while over the whole he put the glass receiver. The arrangement is shown in the annexed illustration:

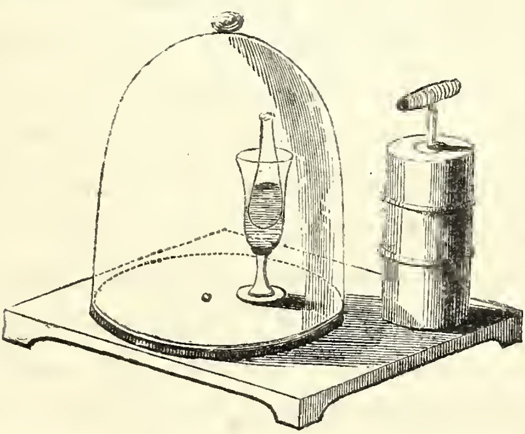


The pump was now set to work, and the air gradually drawn out from the glass receiver, whereupon the thermometer was observed to sink; for as the pressure of the atmosphere was removed the evaporation from the water was increased, while the oil of vitriol at the bottom served to absorb the vapour as fast as it was produced: so that, though the temperature was considerably lowered, the evaporation from the water ultimately became so rapid that it had all the appearance of boiling, and in the course of 5 or 10 minutes the liquid was converted into ice.

Before the solidification took place, however, the thermometer was observed to fall several degrees below the freezing-point, whilst at the moment of its freezing it rose to 32°, in consequence of the escape of the heat which had previously served to keep the water liquid.

The explanation of the process is almost obvious. As in the case of the steam issuing from the Papin's digester, that part of the water passing off in the form of vapour abstracted heat from the remainder of the fluid portion, which, thus losing the caloric that served to keep it liquid, became solid, or froze.

Humphry was now anxious to see what effect the simultaneous evaporation of ether and water would produce under the air-pump. Accordingly he procured a thin glass flask, and this he inserted in a tumbler, so that it fitted almost close. Having poured a little ether into the flask, and some cold water into the tumbler, he placed the whole apparatus under the receiver of the air-pump, as here represented:



On exhausting the receiver the ether was observed to *boil*, from the rapidity of its evaporation, while the water in which it was immersed soon became solidified, or converted into *ice*.

The apparent anomaly of two liquids made to *boil* and *freeze* at one and the same time puzzled the lad for a while. At length, however, he divined the reason. The ether, in passing into the form of vapour, required a certain amount of heat to sustain it in that state, and this it absorbed principally from the water that surrounded it, which soon became congealed owing to the loss of that portion of heat which was requisite for its maintenance in a fluid form.

Humphry had now discovered that, by removing the pressure of the atmosphere, the evaporation of liquids proceeded at a much greater rate, and he was anxious to learn whether they could be made to boil at a lower temperature by the same means.

Accordingly, he fitted a stop-cock into the neck of a Florence flask, and then turning the cock on, so that the vapour might escape, he proceeded to heat the water, over the flame of a spirit-lamp, till it boiled; whereupon he removed the flask from the flame and closed the cock. The liquid then soon ceased to boil; on plunging the flask, however, into a vessel of *cold* water, he found the ebullition instantly to recommence, but to cease again directly the vessel was held near the *fire* or over the *lamp*. Now during the boiling, in the first instance, all the air above the liquid had been driven out of the flask, and replaced by an atmosphere of steam; this, upon plunging the vessel into cold water, had become condensed into a liquid form, so that a vacuum being formed above the water, the fluid boiled at a lower temperature under the diminished pressure. On removing the flask, however, from the cold medium, a new atmosphere of steam was generated, and the pressure of this on the surface of the liquid prevented its boiling any longer; and thus the water was made to *boil by being cooled, and to cease boiling by being heated.*

Humphry afterwards ascertained, that if a glass of water of the temperature of 90° or 100° be placed under the receiver of an air-pump, and the pressure of the atmosphere removed by exhausting the air, the water boils violently at that temperature, and continues to do so until the whole receiver becomes filled with the vapour; which then, pressing upon the surface of the liquid, again prevents its ebullition. By continuing to pump out the vapour, however, the boy was enabled to keep the water boiling at no less than 112° below its boiling-point in the open air.

With alcohol and ether, however, it was not even necessary to warm them, for these fluids boil under the air-pump at all ordinary temperatures.

It has likewise been found that water boils at less than 212° upon the summits of hills and mountains, where the pressure of the atmosphere is considerably diminished. At the top of Mont Blanc water has been made to boil at 187°, and even when the air is lighter at the surface of the earth the boiling-point of all liquids is reduced; so that in this country, where the density of the atmosphere fluctuates considerably, water boils sometimes at 2° lower than 212°, whilst on heavy days it requires to be raised to 214° in order to produce ebullition. Even the cleanliness of the vessels in which the liquid is heated has been ascertained to alter the boiling-point. In glass vessels, from which all chemical and mechanical impurities have been removed by perfect cleaning, water may have its temperature raised as high as 220° without being made to boil; whereas a few metallic filings, or other finely-divided or insoluble materials, have the effect of causing it to boil at a lower temperature than 212°.

Humphry would now have sought to learn how much water becomes expanded in passing into the form of steam. But, though he made several rude experiments on the subject, he was unable, from the want of proper apparatus, to arrive at any definite result, and so was obliged to rest contented with the knowledge which his books afforded him; viz. that a cubic inch of water becomes converted, at

212°, into very nearly a cubic foot of steam, the expansion being about 1700 times the bulk of the original fluid.

Spirits of wine, on the other hand, expand only 493 times, ether about 212 times, and oil of turpentine 192 times; each at the temperature of 212°. Steam, however, is lighter than air—whereas the vapours of spirits of wine, ether, and turpentine, are much heavier than it, the last being nearly 5 times the density of our atmosphere at the same temperature.

Before quitting this part of the subject, there is one striking anomaly connected with the production of vapour that deserves mention here, though it is but a recent discovery.

If a silver, or other metal spoon, be heated to redness in the flame of a lamp, and some water be dropped into it while red hot, it will be found that the liquid, instead of passing off at once into steam, will instantly assume a globular, or spheroidal form, and float about the heated metal, revolving with rapidity, and evaporating very slowly; while the *temperature of the liquid will remain constantly below the boiling point*—so long as the red heat is maintained. If, however, the lamp be withdrawn, the water, as the spoon cools down, will suddenly be made to boil with violence, and be dissipated in vapour with almost explosive energy.

The cause of this singular phenomenon is, that the water is separated from the red-hot metal by an atmosphere of highly-elastic steam, which is generated immediately the liquid is projected on the heated surface, and which, encircling the water, serves to keep it in a spheroidal, or globular state; whilst the vapour, being a bad conductor of heat, prevents the temperature of the hot metal being communicated to the fluid in connexion with it.

This is the reason why water, when accidentally dropped upon the heated bars, or hobs of a grate, is occasionally observed to run along them like globules of quicksilver. If these, however, be smartly struck with a hammer, so as to bring them suddenly into contact with the hot metal, the globules will be instantaneously converted into steam, and the change of form attended with a slight explosion.

Another form of the same singular phenomenon consists in plunging a mass of white-hot metal into a vessel of cold water, when the incandescence will be found to continue, rather than to be quenched, in the liquid, the metal still shining with a bright white light, while the water may be seen to circulate around, though at some distance from, the glowing mass, being separated from it by an atmosphere of non-conducting vapour, which, for a time, prevents its heat being communicated to, and so reduced by, the surrounding fluid. At length, as the metal cools, the water around it is brought into contact with the heated surface, when it is made suddenly to boil with energy.

Moreover, if an iron shell containing water be made red hot, and a hole then drilled in it, no water will be found to flow through the orifice until the iron has been considerably cooled, when it will suddenly issue forth with great violence, in the form of steam.

So, again, if water be poured upon an iron sieve, the wires of which have been heated to redness, it will not pass through the interstices. As the sieve cools down, however, it will be found to run through rapidly.

Further, if a red-hot cinder be let fall into a pan of water, it will be seen to swim upon the surface, and then to sink with a hissing sound, accompanied with a sudden irruption of steam.

But a far more striking illustration of this strange property consists in heating to redness a silver or platinum capsule (or small crucible), and filling it while red hot with a freezing mixture, when the whole mass will instantly be thrown into the spheroidal state, and on introducing a thermometer therein the temperature of the liquid will be found to be scarcely increased, so that a small tube filled with water soon becomes frozen when immersed in it; and *thus ice may thus be produced even in a vessel, the heat of which is no less than* 1000°. Indeed, by introducing some ether and solid carbonic acid into an incandescent crucible, even quicksilver itself has been made to freeze in it, though this requires a temperature of 82° below the freezing-point of water; and yet this extreme cold (equal to that of a Polar winter) has been produced, *and mercury frozen inside a red-hot vessel.*

Humphry, however, was anxious not to conclude his investigations concerning the changes of form produced by heat without ascertaining whether all bodies, in passing from a lower to a higher temperature—or, on the other hand, from a higher to a lower one—absorbed the same quantities of caloric; that is to say, did one body require a *greater amount of heat* to raise it to a given temperature than another, and did some bodies give off more heat than others in cooling?

First, the lad dealt with equal quantities of the *same* fluid at different temperatures, in order to determine whether, on mixing the two together, the resulting temperature amounted to the *mean* of both. He added $\frac{1}{2}$ pint of cold water at 50° to $\frac{1}{2}$ pint of warm water at 100° and found that the two together gave a *mean* temperature of 75° $\left(\frac{100+50}{2}\right)$; so that the hot water had lost 25°, whilst the cold had gained precisely the same amount.

Then Humphry proceeded to try whether the result was the same with equal quantities of *dif-*

ferent fluids. Accordingly, he took the same amount of water at 50° as he had previously employed for one portion, but, instead of the water at 100° for the other, he substituted a like quantity of *quicksilver* at the same temperature, and found to his astonishment, on pouring the one to the other, that the heat of both together was no longer the mean of the two (or 75° as before), but only $66\frac{2}{3}$°. In this case, therefore, the quicksilver had lost as much as $33\frac{1}{3}$° ($100-66\frac{2}{3}$), whilst the water had gained only $16\frac{2}{3}$° ($66\frac{2}{3}-50$); so that *the quicksilver had parted with twice as much heat as the water had absorbed.* Consequently it was evident that, in order to raise a certain *measure* of water to a given temperature, it required just *double* the quantity of heat to be added to it that *an equal measure* of quicksilver did; or, in other words, the capacity of water for heat was twice that of quicksilver.

This referred, however, only to equal *measures* of the two fluids; so Humphry wished to ascertain whether the effect would be the same with equal *weights* of them. He mixed, therefore, 1 pound of water at 50° with 1 pound of quicksilver at 100°, and discovered that the resulting temperature was not quite 52°. Here, then, the quicksilver had lost rather more than 48° of heat, while this amount had served to increase the warmth of the water only about 2°. There was but one conclusion to be arrived at, therefore; namely, that the capacity of a given *weight* of water for heat is about 30 times greater than an *equal weight* of quicksilver, whereas the capacity of a given *measure* of the former is only twice that of an equal measure of the latter.

After this the boy added 1 pound of water at 50° to an equal *weight* of spermaceti oil at 100°, when the temperature of the mixture was found to be $66\frac{2}{3}$°; so that the oil had parted with twice as much heat as the water had gained.

Thus it was evident that different substances required *different* quantities of heat to raise them to the *same* temperature; and that in order to warm a certain *weight* of water to the same degree as an equal weight of oil and quicksilver, twice as much heat must be given to the water as to the oil, and 30 times as much as to the quicksilver.

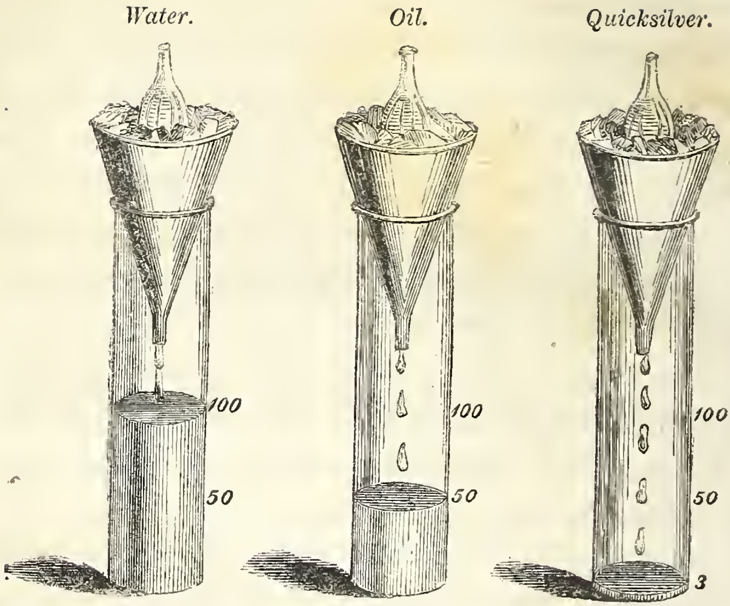
Still the cautious boy was anxious to test the truth of this result by another experiment.

Accordingly, he took 1 pound weight of each of the three substances above mentioned, and having brought them severally to a temperature of 50°, he placed the flasks in which they were respectively contained in a large bath of warm water, the heat of which he kept constantly at 100°. This done, he proceeded to note the time and manner in which each of the fluids was heated, and found that when the thermometer in the quicksilver had reached 80°, that in the oil stood at 52°, while the one in the flask of water marked only 51°; and, though the three liquids ultimately attained the same temperature as the water-bath in which they were immersed, *the water took* 30 *times longer to acquire that heat than the quicksilver, and twice as long as the oil.*

Now it was manifest that each of the liquids in this experiment must have been receiving heat alike, so that the only feasible explanation was that the water, in order to have its temperature raised to a given degree, required 30 times the quantity of heat that the metallic fluid did, and double the quantity of the oleaginous one.

Nevertheless, to avoid all possible chance of error, Humphry repeated the experiment in another form, so as to see whether, in cooling, the water would part with more caloric than either the oil or the quicksilver; and just as much more, too, as it had been found to imbibe while being heated.

With this view Humphry filled three Florence flasks—one with a pound of water, another with a pound of oil, and the third with an equal weight of quicksilver—all at the temperature of 212°, and having placed each of the flasks in a large funnel, that rested on a graduated glass jar, he surrounded them one after another with pounded ice, as here shown:



When the fluids had been severally cooled down to the same temperature as the ice around them, the lad proceeded to ascertain, by the quantity of water produced by the thawing of the ice surrounding each flask, how much heat had been given out by the three liquids respectively, in sinking from 212° to 32°; and he ultimately found that the hot water, in cooling, had thawed twice as much ice as the hot oil, and 30 times as much as the equally hot quicksilver. Hence it was beyond doubt that water, at a given temperature, *contained considerably more heat than either of the other fluids*, and hence the reason why it took a longer time than they to be warmed or cooled to the same extent.

These experiments naturally led the boy to think how great a magazine of heat the sea must be, and what a beneficial influence its slow rate of heating and cooling must have in equalizing the temperature of the atmosphere. Quicksilver, on the other hand, however, having a small capacity for heat, and, consequently, being quickly warmed and cooled, becomes of great value as a liquid for the thermometer, since it is this property that gives great sensibility to the instrument.

It now only remained for Humphry to ascertain the relative capacities for heat among solids. This he did by cooling down equal weights of the metals and other bodies under the exhausted receiver of his air-pump, and noting how long they took to pass each from a like higher to a like lower temperature.

By such means the youth ascertained that *Lead* had the smallest capacity for heat among the metals, cooling more rapidly than even quicksilver itself, and 34½ times quicker than water. Next in order came *Platinum*, which again had less capacity than quicksilver, and cooled 32¼ times quicker than water. After this, *Silver* was found to cool 18 times quicker than water; *Zinc*, 10¾ times; *Copper*, 10½ times; and, lastly, *Iron*, which was ascertained to part with its heat only 9 times quicker than water. Glass, however, was found to occupy a longer time in cooling than any of the metals, giving off its caloric but $8\frac{1}{2}$ times quicker than water; while sulphur, on the other hand, retained its warmth longer even than glass, but still cooled $5\frac{1}{3}$ times quicker than water.

The capacities for heat, therefore, among the above-mentioned substances, were inversely as their rates of cooling: that is to say, lead, which cooled the quickest, contained the least quantity of heat, and, therefore, required less caloric to raise it to a given temperature; while sulphur, on the other hand, which took nearly 7 times as long to cool as lead, contained 7 times more heat, and required to be warmed for just so much longer a period.

The relative capacity for heat among substances is generally termed their "SPECIFIC HEAT;" for as different bodies are found to possess *unequal quantities of heat at equal temperatures*, and as this exists in them in a *latent* or *insensible* state, the term specific heat has therefore been adopted to express *the relative amount of latent caloric existing in different substances at the same temperatures.*

CHAPTER X.

THE WONDERFUL EFFECTS OF HEAT—(*concluded*).

THE young philosopher had now investigated the effects produced by an elevation of temperature, not only upon the *bulk*, but upon the *form* of different bodies. He had found, first, that heat increased the size of certain substances, without destroying the cohesion among their constituent particles; and, secondly, that it loosened the attraction between the atoms of other substances, and rendered them free to move: so that solids became converted by it into liquids, and liquids into vapours, while the heat which was absorbed and disappeared during the production of such changes he had ascertained not only to exist between the molecules of the resulting liquid or vapour in a *latent* or insensible state, but to be again evolved in a sensible form when the vapours became condensed or the liquids solidified.

The next step, therefore, was to study the circumstances regulating the *ignition* and *combustion* of bodies.

That there is an intimate connexion between the principles of light and heat, Humphry had little doubt. Indeed, it was plain to him that the two are mutually disposed to produce each other. He had, however, as yet considered only the laws of heat, divested of luminosity; but, at present, he was about to examine the one in connexion with the other; the laws of ignition and combustion being those of the production of artificial heat, accompanied with light *for the time being.*

Whether substances, when *merely warm*, are capable of emitting rays of light, it is impossible to determine; "but," said the lad to himself, "the slightest increase of temperature is perhaps accompanied with some kind of luminous power that our sense of vision is incapable of perceiving, since it is only when the temperature of bodies is raised to a high point that they acquire the property of becoming luminous to our eyes."

It is extremely difficult to ascertain the precise temperature at which bodies, when heated, acquire the property of giving out light; for the result is greatly modified, not only by the sensitiveness of the eye of the observer, but also by the clearness of the atmosphere at the time of making the experiment.

The amount of heat necessary for producing luminosity, however, certainly exceeds 650°, since this is the temperature at which quicksilver boils;

and though Humphry heated the metallic fluid to ebullition in a dark room, it did not become, so far as he could detect, in the least degree luminous.

Subsequent experiments, however, induced him to place the degree at which heated bodies begin to emit light in *the dark* at 810°; though the investigations which have since been made in connexion with the subject lead to the conclusion that the first gleam of light which is given out from a heated platinum wire occurs at a temperature of about 865°. The luminous rays emitted at this heat, however, are not red, but of a *lavender-grey* colour (similar to those which exist in the solar spectrum beyond the violet band), and seem to be the first transition from darkness to ordinary light.

At the temperature of about 1000° the light emitted by the heated body becomes *visible in daylight*, and is then of a dull-red hue.

At 1200° the tint of incandescence brightens into a vivid crimson, or "cherry-red," as it is termed.

Then, as the temperature increases, the light emitted by the glowing body assumes partly a *yellow* colour; so that at 1700° an "*orange* heat," as it is called, is produced.

At length, however, when the heat rises to the highest point, the light emitted acquires such brilliancy as to be painful to the eye; the incandescent substances then appearing no longer tinted, but positively colourless in the fire. This constitutes what is denominated a "*white* heat," and occurs at no less a temperature than 3000°.*

At this intense temperature a remarkable change is found to occur in the character of the heat itself, for it has been before shown that the heat-rays emanating from an ordinary fire are stopped by glass; so that while the light emitted by the burning coals passes freely through plates of glass, and is capable of being reflected by glass mirrors, like the light of the sun itself, the *heat* radiated by them—*unlike that of the solar beams*—has neither the power to traverse the transparent substance, nor is it susceptible of being concentrated into a focus by reflexion from a glassy surface.

Artificial heat, however, *when at a very high temperature*, is found to have all the properties of solar heat. Not only does it then admit of being focussed by burning-glasses in the same manner as the sunbeams, but the light emitted by it darkens solutions of silver as effectually as the light of day; so that (as more recent experiments have proved) a photographic portrait can be taken as well by the rays from coke at a white heat, as they can by the rays of the sun itself.

But only those substances are capable of being

* The highest temperature of a good blast-furnace is, according to Daniel, about equal to 3300°. This constitutes a "high white heat."

rendered incandescent, which have power to sustain the high temperatures requisite for ignition, without being vaporized or decomposed by the heat. Many bodies, however, are either dissipated or destroyed long before they attain this intense temperature; while, on the other hand, those termed combustibles, when heated in the air, *burst into flame*, and undergo what is termed *combustion.*

"Now what *is* combustion?" said Humphry to himself, as he thought over the subject. "What are the phenomena which occur when substances burn with the evolution of flame?"

The boy knew, that formerly it was supposed bodies owed their combustibility to the presence of a certain principle called "phlogiston," which during combustion, said the philosphers, escaped from them, producing light and heat; whereas when the bodies had lost their phlogiston—and had become "dephlogisticated," as it was termed—they ceased to be combustible.

Phlogiston, however, Humphry was well aware, was a purely imaginary principle, of whose existence no proof had been given, and which had been invented merely to explain a process that appeared to be otherwise incomprehensible.

Moreover, Humphry had learnt from the books he had already read upon the subject, that the metals were increased in weight after being burnt; so that it was impossible to attribute the combustion in such cases to the escape of phlogiston, since it was inconceivable how a body could be rendered *heavier* by *losing* something which had previously been combined with it.

Nevertheless, the belief in this visionary phlogiston had continued for nearly half a century; and it was only in the year 1775 that more correct views had been propounded concerning the process.

At the time of young Davy's commencing the study of this subject, Lavoisier's new theory of combustion had been in existence but a few years, and the boy having obtained from Mr. Tonkin the loan of the treatise in which the more correct views were originally propounded, had eagerly perused the volume, being not a little delighted with the precision of reasoning and the boldness of speculation contained in it.

Still Humphry was not satisfied with merely reading and acquiring the ideas of others. He criticised the theoretical speculations of the great French philosopher, doubted, and rejected, and advanced speculations of his own, while speculation led him to experiment.*

* The above is Dr. Davy's account of his brother's first chemical studies: "Such was the commencement of Humphry Davy's career of original research," he adds, "which in a few years, by a succession of discoveries, accomplished more in relation to change of theory and extension of science than, in the most ardent and ambitious moments of youth, he could either have hoped to effect or imagined possible."

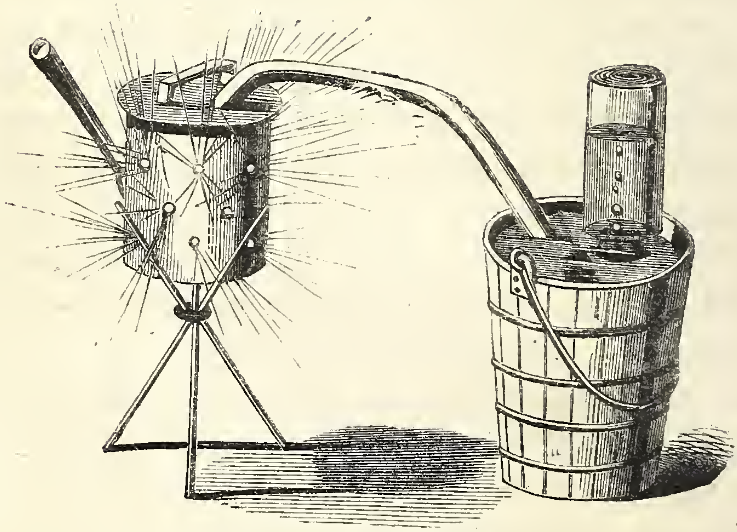
Humphry began the investigation of the phenomena of combustion by an experiment, to prove that the air in which combustibles are suffered to burn till they are extinguished undergoes a very remarkable change.

For this purpose the lad put a little water in a soup-plate, and on it he placed a small piece of candle, so that it might swim on the surface. Having lighted the wick he covered it over with a large tumbler, and found that the candle then burnt only for a short time, whilst immediately the flame was extinguished the water rose in the tumbler considerably above its level in the soup-plate.

Hence it was evident, that the portion of the air which was necessary for combustion had been removed by the burning candle from the atmosphere confined within the tumbler, and that, therefore, it was no longer capable of sustaining the flame.

"But maybe," thought Humphry, "the candle, in burning, gives off some gas, which is prejudicial to combustion."

So, to satisfy himself whether such were the case or not, the boy burnt some charcoal in an old iron saucepan, that he had previously drilled full of holes, in order to admit the air. Then, having fitted a tin tube into the lid of this, he, by means of the chimney so formed, conducted the gas evolved by the burning charcoal into a wide-mouthed bottle, that he had previously filled and placed with its mouth downwards, on a perforated stand in a pail of cold water; so that as the combustion went on the gas produced kept bubbling up in the pail from the end of the tube, and displacing the water as it rose into the inverted bottle that stood immediately above it. The arrangement, however, will be more readily comprehended by reference to the subjoined engraving:



As soon as sufficient gas had been collected Humphry removed the tube from the pail, and corked the bottle under water; then having set the bottle of gas on a table, he attached a piece of candle to the crooked end of a long wire, and lowering this, while alight, into the gas, found, to his astonishment, that the flame was immediately extinguished.

"So then," cried the delighted boy, "here is a kind of air that I can neither see, nor feel, nor smell, and yet it extinguishes burning bodies like water."

But Humphry was too eager to examine the properties of the gas he had collected to wait to reflect upon the curious results it afforded him. Accordingly he procured a tall glass jar, and having placed a piece of burning candle at the bottom of this, he proceeded to empty the gas from the bottle into the jar, when to his surprise he discovered that he could pour out the heavy air that had come from the burning charcoal as though it had been a liquid, while, immediately it fell upon the lighted candle at the bottom of the jar, the flame disappeared as suddenly as if so much water had been showered upon it.

After this the boy amused himself by decanting the gas backwards and forwards from one vessel to the other, and ultimately found that it was instantaneously fatal to animals, destroying sentient life as rapidly as it extinguished burning substances.

Humphry's next step was to discover what substance was capable of readily absorbing this gas, and after many trials he found that lime-water did so with great facility.

Accordingly he added about an ounce of quick-lime to a quart of water in a glass bottle, and corking it up closely he shook it several times, so as to dissolve as much of the lime as possible; after which he allowed it to settle, and then decanted off the transparent and colourless liquid into a clean bottle with a glass stopper. This transparent solution of lime in water he then poured into the glass jar containing the gas from the burning charcoal, and having corked the vessel tightly up, he shook it about, and immediately perceived that the lime-water was rendered turbid by the gas, being no longer clear and transparent as before, but changed to an opaque milky white; then having filtered the turbid water, and so separated from it all the white particles that had rendered the solution opaque, he dried and weighed the sediment, and found that the quantity of lime which had been dissolved by the water had become nearly doubled in weight by the gas which it had absorbed.

The youth had now learned how to remove the products of combustion, and he was consequently in a position to determine whether the air, after a substance had been burned in it, really had or had not been deprived of anything during the process.

Humphry therefore placed a small quantity of lime-water at the bottom of a wide-mouthed bottle, and through the cork of this he passed one end of a long wire, while to the other end of it he attached a small piece of wax taper. This he lighted, and then lowered down into the air that stood above the lime-water in the vessel. The cork was now forced tightly into the mouth of the bottle, and in a minute or two the taper was extinguished. After this the jar was shaken well up, when the youth beheld, to his great delight, the lime-water rendered turbid by the gas evolved during the burning of the taper.

The next step was to discover whether the air which remained in the bottle (and from which the products of the burning taper had been removed by the lime-water) was still capable of sustaining combustion.

Accordingly another lighted taper was lowered into it, but this was as rapidly extinguished as the one had been by the gas from the burning charcoal itself. It was afterwards found, too, that that part of the air which remained after combustion was as destructive of animal life as even the charcoal gas had been discovered to be.

"How wonderful!" exclaimed the boy, "that the atmosphere round about us should be made up of two different kinds of air—one that enables combustibles to burn and animals to live in it, while the other immediately extinguishes flame and destroys sentient life! How can I collect that portion of the air which supports combustion and maintains life, *apart* from that which puts an end to it? I should like to see what it would do by itself, and whether substances would burn brighter in it alone; for surely such must be the case, since in the atmosphere it is mixed with another kind of air that extinguishes flame and destroys living creatures, so that the one must constantly be counteracting the effects of the other."

Humphry racked his brains for a long time for the means whereby to separate the two kinds of air from each other. At last he remembered one of Lavoisier's experiments in connexion with the subject, and immediately set to work to repeat it.

With this view the lad obtained some "calcined mercury," for this substance he knew to have been produced merely by burning metallic mercury for a long time in a tube exposed to the air, so that the portion of the atmosphere which supported combustion (instead of being evolved in a gaseous form, as in the case of the burning charcoal) had become *fixed, or rendered solid,* in the "*calx*" which resulted from the process. The boy was therefore anxious to see whether it were not possible, by burning the calcined product once more, to drive off that portion of air which had been taken up by it during the previous burning, and so to discover what are the peculiar and distinctive properties of the air which had been absorbed. Consequently, he submitted some of this calcined mercury to a red heat in a retort, and collected the gas that was given off from it in a wide-mouthed bottle from which he had cut off the bottom. This, having corked, he filled with water, and stood on a perforated ledge in a pail—the gas being collected as before described. When the water had all been displaced from the bottle, and it was consequently full of gas, Humphry slid it, while under the water, off the ledge into a soup-plate, and then, removing it to a table, proceeded to investigate its properties.

Here, then, he had a jar-ful of the gas (named *oxygen* by chemists) that maintained the combustion of bodies in the open air, and separate, too, from the other gas, which tended rather to retard their burning in the atmosphere.

Humphry's first experiment was to introduce into the gas thus obtained a lighted taper, placed at the end of the wire as before, and the boy was enraptured as he beheld the flame immediately enlarge (instead of diminishing, as when confined in a jar of mere atmospheric air), and become intensely bright, while the combustion proceeded at so rapid a rate that the piece of taper itself was soon consumed. Then another piece of taper was used, but this was blown out immediately after being lighted, so that the wick was merely glowing on its introduction into the gas. On being plunged into the jar, however, it was instantly re-kindled, and burst into the same vivid flame as before.

Next, the combustion of *sulphur* was tried in the gas. This substance burns in the open air, as is well known, with a small blue flame. On placing a small piece of lighted sulphur, however, in a copper capsule attached to the end of a long wire, it was no sooner lowered into the jar than it began to burn with a beautiful purple or lilac-coloured light, the flame becoming suddenly enlarged, and the sulphur itself appearing to dissolve in the gas. At the conclusion of the experiment the water in the soup-plate, in which the jar stood, was set carefully on one side, for after-examination.

After this the lad tried the combustion of *phosphorus* in another jar of gas, in the same manner. Humphry knew the combustion of this to be very vivid, even when inflamed in the atmosphere; so, to prevent accidents, he used in the jar a piece not larger than a pea: but even this, when lowered alight into the gas, produced so intensely white a flame that he could scarcely bear to look at it, while clouds of white flaky matter were evolved from it like smoke; the heat, too, was so great, that he was afraid the jar would crack: and so it would have done, had he not, luckily, employed a very large one.

The young experimentalist was overjoyed at the splendour of the combustion of these substances, and longed to see whether it were possible to burn the *metals* by such means. So, having made another jar-ful of the same gas, and placed it over some water in a soup-plate, he took a piece of watch-spring, and when he had affixed the sulphur tip of a match to the end of this, he lighted the match and plunged the whole into the gas. He was soon well repaid for his pains; for in a short while the metal burst into vivid combustion, throwing off a shower of the most brilliant sparks, which played around it like a fountain of fire, whilst goutes of the white-hot metal fell hissing through the water, and lay beneath it for some time, red hot upon the plate, the glaze of which was afterwards found to have been even fused at the points where the molten iron had fallen upon it.

But the boy's rapture on beholding the wonder of combustible iron was not altogether unmingled with fear; for the heat produced by the burning of the metal was so intense, that he grew nervous lest the glass jar should break during the experiment. He was wise enough, however, to hold it in his hand, so as to allow a little of the gas to escape, as well as to prevent the jarring of the glass on the plate beneath.

Humphry was now nearly exhausted with his labours, and it was time to reflect upon all that had occurred.

In the first place, then, it was certain that a considerable quantity of the gas used in these experiments had disappeared during the combustion, for the water had each time risen in the jar above the level of that in the soup-plate. "What, then, had become of the lost gas?" he asked himself. There was but one answer—*It had combined with the burning body, and formed a new substance with it.* In the case of the burning sulphur, the water that had been in the soup-plate below the jar was found, on examination, to be sour to the taste, and to redden vegetable-blue colours; so that here the gas had combined with the combustible and produced an *acid* that was soluble in water. Again, with the burning phosphorus, the white flakes that had been evolved during the combustion had been ultimately dissolved by the water, which likewise tasted sour, while it stained vegetable colours in the same manner as the sulphur product did; whereas, in the case of the burning iron, the metal appeared to have been rusted, for the particles remaining at the bottom of the soup-plate were found, after the experiment, to have lost their metallic nature, and to have assumed all the character of a "*calx*," or *rust*.

"Well, then," said the lad, "it seems that during combustion one part of the air combines with the burning bodies, and so either *rusts* or *acidifies* them." In confirmation of this view, he recollected "that the gas evolved from the burning charcoal also gave a slightly sour taste to the water it passed through."

"Still," mused Humphry, "if a part of the air really *does* combine with the combustible burning in it, the result, of course, should be, that the combustible, after being burnt, should be *heavier* than before—even as the lime with which I absorbed the gas from the burning charcoal became greatly increased in weight by it."

The youth was not long in putting this part of the matter to a practical test. Having accurately weighed a small quantity of calcined mercury (which, as we said before, he knew to be a rust of the metal), he set to work again to make it red hot, and to drive off the air with which it had previously been made to combine while burning. This gas he collected in a small glass jar, open at the bottom, and having a stop-cock at the top of it. Then the boy took a thin hollow ball of glass, which had also a stop-cock fitted to it. Having screwed this on to the metal plate of his air-pump, he exhausted the glass ball as entirely of air as he could, and then closing the cock he detached it from the pump, and proceeded to ascertain the weight of the ball now that it was divested of air. This done, Humphry screwed the stop-cock of the glass ball on to that of the glass jar in which he had collected the gas from the calcined mercury; then, turning on both the cocks, the gas rose from the jar into the ball, and when the jar itself was full of liquid, and all the gas had consequently been removed from it, he closed the stop-cock once more, and, unscrewing the glass ball from the jar, proceeded to ascertain how much the ball had gained in weight, now that it contained the whole of the gas evolved from the calcined mercury.

The next step was to weigh the mercury itself. This, however, was no longer the red powder that it was before the gas had been driven off from it, but had now become "reduced" into so much bright liquid metal; and on being put into the scales it was found to have lost just as many grains in weight as the gas, which had been collected from it, required to balance it in the scales.

But this was not enough to satisfy the cautious young experimentalist, for he still desired to see whether, if the same quantity of metallic mercury were burned in the same quantity of gas, the resulting compound of the metal and the air would weigh exactly as much as the air and the metal did separately.

Accordingly, Humphry proceeded now to burn the metallic mercury in the gas, and so to cause them to combine once more. By keeping the metal at a red heat with the gas above it, the combination was at length effected, and then, on weighing the red "calx," or rust, that resulted from the process, it was ascertained to be precisely as heavy as the metal and the gas had weighed when separate.

Here, then, it was manifest that substances by *burning were increased in weight, and that they were* *just as much heavier after combustion as the weight of the quantity of air which had been absorbed by them during the process.*

"Is it true, therefore," mused the boy, "that the candle and the coals, which appear to us to be destroyed by combustion, become positively increased in weight by it?"

The experiment which Humphry had already performed in collecting the gas from burning charcoal assured him that such was positively the case, for he knew that this gas, though invisible, had an absolute weight, being so much heavier than the atmosphere that it admitted of being poured, like water, from one vessel to another. The experiment with the calcined mercury, moreover, told him, that if he had weighed the charcoal before it was burnt, as well as the quantity of air which it had consumed while burning, he would have found the whole of the gas which resulted from the combustion would have been precisely as heavy as the air and the charcoal added together.

For the same reason, if the gases evolved from a burning candle were to be collected, they, likewise, would be found to be heavier than the candle itself; and just as much heavier, too, as the quantity of air which had disappeared during the combustion.

Combustion, therefore, was merely the rapid combi-

nation of a portion of the air with a combustible body, accompanied with the evolution of heat and light.

Still Humphry could not quit the subject without examining the conditions which were necessary to produce such a combination. *The principal requisite was manifestly elevation of temperature.*

Some substances, however, inflame at ordinary temperatures—immediately on entering the atmosphere—as, for instance, the gas called "*phosphuretted hydrogen.*" This was a new discovery in young Humphry's time, and the boy delighted to produce the gas by heating a small quantity of phosphorus in a retort completely filled with a moderately strong solution of caustic potash—the heat being carefully applied until the solution boiled, while the beak of the retort was kept under the shelf of a water-bath. Upon coming into contact with the air, Humphry saw the bubbles of gas, as they left the surface of the water, suddenly inflame, with a slight explosion; and as the atmosphere was still, each bubble, on bursting, produced a beautiful expanding ring of white smoke.

It is this gas which gives rise to the production of those lights in the air which are known by the names of "*ignes fatui*" ("*will-o'-the-wisps,*" or "*Jack-o'-lanterns,*") and "*corpse-candles*"—the former appearing over marshes, and the latter being seen to rise from recent graves—but both alike proceeding from the decomposition of organic matter.*

Again, *phosphorus dissolved in sulphuret of carbon* produces a spontaneously inflammable solution; so that if a small quantity of the liquid be poured on a piece of paper it evaporates rapidly, and leaves the phosphorus behind, which immediately bursts into flame.

The same phenomenon of spontaneous combustion also occurs with the substance called "*pyrophorus*." This is generally formed of *powdered alum* heated with an equal weight of brown sugar or honey. After the materials have been melted and well mixed in an iron ladle, they are made red hot in a phial coated with clay, and placed in a crucible of sand—the heating process being continued until a blue flame appears at the mouth of the bottle; this is allowed to burn for about five minutes, when the phial is well stopped and removed from the fire.

The compound, on being cooled and exposed to the air, is spontaneously combustible.

Sulphate of potassa, likewise, when heated to redness with half its weight of lamp-black, forms a compound, which takes fire immediately on exposure to air.

* A chemical philosopher in America ignited a piece of paper by one of these lights on a still night. The breath, however, had to be held during the operation, for the least agitation of the air wafted them from the spot.

Again, *tartrate of lead,* heated to a dull red in a glass tube, forms, when cool, a very perfect pyrophorus, which immediately inflames on being shaken out into the atmosphere. Further, when *iron is in a state of extreme mechanical division*—such as very fine powder—its affinity for the oxygen of the atmosphere is such that it heats, and even ignites, on exposure to the air. This is the case with the finely-divided metal as obtained by the action of hydrogen gas upon red-hot iron-rust, so that, when suffered to cool in this gas, the iron is as spontaneously oxidizable as even *potassium itself.*

Moreover, if a small piece of *spongy platinum* be held in a jet of hydrogen, issuing from a small tube into the atmosphere, the platinum immediately becomes red hot, while the gas itself bursts into flame.

Platinum wire, or *foil,* if the surface be perfectly clean, acts so rapidly at common temperatures on a mixture of oxygen and hydrogen gases (mixed in the proportion of 1 to 2), that it often becomes red hot on being introduced into a vessel containing them, and kindles the mixture. Handling the platinum, however, wiping it with a towel, or exposing it to the atmosphere for a few days, suffices to soil the surface of the metal, and so to prevent its action.

Finally, a piece of the metal called *potassium* (procured from *potash*) has so strong an affinity for oxygen, that when thrown upon water, at ordinary temperatures, the metal decomposes it the instant it touches the liquid, and so much heat is disengaged that the potassium is inflamed, and burns vividly while swimming on the surface. The same spontaneous combustion ensues, indeed, with *ice*—so that the cold body appears to heat the metal even to inflammation.

But a still more curious instance of spontaneous inflammation is to be found in the sudden explosion of a mixture of *Chlorine and Hydrogen gases when exposed to sunshine;* for though the two gases, when mixed together in equal volumes, may be preserved without change in a dark place for any length of time, nevertheless, immediately they are submitted to the direct solar rays, the whole mixture becomes suddenly inflamed, and a violent explosion ensues.

Next to those substances which are spontaneously combustible comes *phosphorus*, which inflames, when perfectly dry, at the low temperature of 60°. Indeed, such is its tendency to combine with the air, that, if free from all moisture, it takes fire by the heat of the hand alone. Slight friction, as when rubbed upon a piece of coarse paper, also produces the same result. It is very difficult, however, to light a piece of paper by the flame of phosphorus, for the paper becomes coated with a crust of the solid *phosphorous acid*, which is produced by the combustion, and serves to protect it from the flame.

There is, likewise, a gas (for the knowledge of which we are indebted to the after-discoveries of Davy himself), called *protoxide of chlorine*, which requires so slight an elevation of temperature to decompose it, that even the heat of the hand is sufficient to cause it to explode with the evolution of heat and light. This gas is produced by the action of hydrochloric acid on chlorate of potash and water, and it is so explosive that it frequently detonates violently in being transferred from one vessel to another. It should, therefore, be dealt with by none but experienced chemists. A small piece of phosphorus let up into it instantly takes fire, and burns with much brilliancy. Sulphur likewise decomposes it with violent detonation, and even a piece of blotting-paper introduced into the gas is sufficient to cause it to be suddenly resolved into its elements.

The gas termed *Binoxide of Chlorine* (called also the *Peroxide*) is even more explosive than the Protoxide. It detonates violently when heated to 212°, emits a strong light, and undergoes a greater expansion then the simple oxide above described.

Again, the *Binoxide of Hydrogen* (or *Peroxide*, as it is sometimes denominated), when heated to 212°, gives off oxygen so rapidly as to cause an explosion, while the rusts (oxides) of some of the metals act upon it with such energy, that, when dropped into it, a violent detonation immediately ensues, and the glass tube on which the experiment is conducted becomes red hot.

Further, the gas called *Binoxide of Nitrogen*, when combined with *sulphurous acid* gas, produced a compound called *Nitro-sulphuric Acid*, which is so prone to decomposition that it cannot be collected in a separate state, and the salts of which are held together with such slight affinity that even a little charcoal powder, or spongy platinum, is sufficient to cause a violent evolution of gas, while at a temperature only a few degrees above that of boiling water, an explosion ensues.

Moreover, the *Bisulphuret* (called, also, the *Persulphuret*) *of Hydrogen*, which is a yellow oil-like liquid, has its elements so feebly united, that at a heat short of 212° it is instantaneously resolved into *sulphur*, and the simple *Sulphuretted Hydrogen* which is evolved in the form of gas, with almost explosive violence. The same effect is produced by the mere contact of most substances—especially the metals, flint, and even the earths in powder—while the oxides of gold and silver are "reduced" by it with such energy that they are rendered instantaneously red hot.

These binary compounds of oxygen or sulphur have most of them been discovered since Davy's time. They are, however, remarkable in possessing kindred affinities, and being severally decomposible at a temperature of 212°.

After these, in the order of ready decomposibility, come the compounds of *Nitrogen.*

The peculiar black powder, called by chemists *iodide of nitrogen*, which is produced by pouring some strong ammonia upon a very small quantity of iodine, is so explosive, that it detonates violently as soon as it is dried; and the slightest pressure, even when moist, produces a similar effect. If put into pure ammonia, it explodes when lightly pressed in that liquid. Heat and light are emitted during the detonation, which is merely a species of instantaneous combustion. So dangerous is this compound, that the most experienced chemists seldom operate on more than a few grains of iodine at once.

The yellow oil-like liquid, called *chloride of nitrogen*, which results from the action of chlorine gas upon sal ammoniac, also enters into instantaneous combustion at very low temperatures; so that, when it is heated to a little above 200°, it detonates with tremendous violence, a vivid flash of light being produced at the same time, while the vessel —which, to prevent accidents, is covered with a wire cage—is broken to atoms. This compound is so dangerous, being one of the most explosive substances yet known, that in dealing with it the face is always protected by a mask, and only a small globule of it, no larger than a mustard seed, experimented upon. Dulong, the French chemist who discovered it, lost an eye and the use of a finger whilst operating with it; and Davy himself, in after-life, was wounded in the face by the effects of its detonation. The mere contact of this substance with certain combustibles causes it to explode violently, even under water, at ordinary temperatures. If touched with phosphorus, India rubber, common oil, turpentine, caustic potash, or even soap, it detonates so violently as to break to pieces the vessel containing it, and to scatter the water in which it is immersed in a shower all around.

Bromide of nitrogen, again, is said to be even more easily decomposed than the chloride. It is a dark-red oily liquid, having a fœtid odour, and giving off a vapour that is very irritating to the eyes. This compound, when touched with phosphorus, or even a small piece of arsenic, detonates with tremendous violence.

Next to the above remarkable compounds of Nitrogen, the *fulminates of the precious metals* (into the composition of which, however, Nitrogen also enters) must be ranked in the order of ready combustibility; for these likewise explode at very low temperatures, with the production of heat and light.

First come the *Nitrurets of Mercury and Silver*

—that is to say, compounds of those metals with Nitrogen. These are formed by the action of Ammonia on the oxide of Mercury or Silver. The Nitruret of Silver explodes with tremendous violence when gently rubbed or heated, and the Nitruret of Mercury when struck with a hammer, or acted upon by strong oil of vitriol.

Fulminating Gold, when suddenly heated to about 290°, detonates with great force and a vivid flash; and if exploded upon platinum foil, the metal is torn at the point of contact. Friction with hard bodies, or an electric shock, also explodes it. The more it is washed and dried, the more explosive this compound becomes; and if long retained at the temperature of boiling water, so as to become perfectly dry, the slightest friction causes it to detonate immediately and violently. If it be moist, however, it does not explode on the application of heat till dried, and those portions which first become dry explode the soonest; so that, in such a case, a succession of detonations is produced.

Fulminating Mercury requires a temperature of 300° to cause it to explode, which it then does with a bright flame. It also detonates by friction, so that the greatest caution is required in preparing and dealing with it. This compound has even been known to explode in a moist state, and in the most careful and skilful hands it cannot be touched without considerable danger.* This is the substance used in the percussion caps; it is introduced into the caps moistened with a little tincture of benzoin, so as to be dropped into them, and then carefully dried. Howard, the discoverer of the compound, endeavoured to substitute it for gunpowder, but the explosion was found to be so sudden that it burst the gun without expelling the shot.

Fulminating Silver likewise explodes, with the evolution of light and heat, at nearly the same low temperature. A grain, or merely half a grain of this substance, detonates with great violence, when heated or when touched with any hard body. On being placed upon a piece of rock crystal, and rubbed in the slightest manner by another crystal, it explodes with great force. It has sometimes exploded upon the contact of a glass rod, even under water; so that merely the feather of a common quill is generally used to collect it. It is dangerous to keep it in a cork-stoppered phial, for serious

* A melancholy proof of this was furnished by the death of Mr. Hennell (the chemist at Apothecaries' Hall) on the 4th June, 1842. He was in the act of mixing two separate portions of the powder in a moist state with an ivory knife, when the whole quantity, amounting to above 6 lbs. exploded, and shattered his head, breast, and right arm to atoms. A man, however, who was standing within four yards of him, was not injured, but the windows of the surrounding buildings were broken; while a large wooden block, upon which one of the basins was placed, was shivered, as was also the pavement on which it stood.

accidents have arisen from its unexpected explosion in a confined state. In short, persons cannot be too careful in meddling with it, and its use for detonating balls and other purposes of amusement is highly perilous and reprehensible.

Fulminating Platinum, on the other hand, explodes at a temperature of 420° with a loud report.

There is likewise a *fulminating powder*, composed of a mixture of 3 parts *nitre* with 1 of *sulphur*, and 2 of dry *carbonate of potash*. This substance explodes with much violence at the low temperature of 330°; so that if a little of the compound be heated up to that point upon a metallic plate, it blackens, fuses, and detonates with great force.

Again, a mixture of 3 parts *chlorate of potash* and 1 of *sulphur* detonates loudly when struck upon an anvil with a hammer, and even sometimes explodes spontaneously. If 2 or 3 grains of chlorate of potash be reduced to powder in a mortar, and some very fine flour of brimstone be then added to it, the two substances, when rubbed together, will detonate with a smart noise, like the cracking of a whip. A mixture of *chlorate of potash* and *sulphuret of antimony* takes fire by gentle trituration, and deflagrates with a bright puff of flame and smoke. Chlorate of potash was proposed by Berthollet (the French chemist) as a substitute for nitre in gunpowder. The attempt was made at Essone, in 1778; but no sooner was the mixture of the chlorate with the sulphur and charcoal submitted to trituration than it exploded with violence, and proved fatal to several persons.

With *phosphorus* and *chlorate of potash* the explosion is dangerously violent: 1 grain of phosphorus with two of the chlorate, if placed in a small piece of paper and struck with a hammer upon an anvil, will immediately explode, and the phosphorus be thrown about in an inflamed state. Gunpowder, again, if mixed with powdered glass and struck with a heavy hammer upon an anvil, almost always explodes.

Moreover, a mixture of *oxygen* and *hydrogen gases*, suddenly submitted to violent mechanical compression, unite with a vivid flash of light and produce water.

Next to Phosphorus and the Fulminates, *Sulphur* is the most easily kindled. This body enters into combustion at about 500°. It is the comparatively low temperature at which sulphur bursts into flame, that makes it so important an ingredient in gunpowder, matches, &c. The easy combustibility of sulphur may be well illustrated by propelling a small quantity of it in powder into the current of hot air issuing from the glass chimney of a gas lamp, when it will be seen to take fire at a considerable height above the flame.

Wood, cotton, paper, &c. require, on the other hand, their temperatures to be raised much higher than that required for the inflaming of sulphur, in order to be made to enter into combustion.* Paper merely becomes brown or scorched at the heat of 440°, nor can it be lighted at a red heat, though the temperature of this is 1000°. Cotton or tow, however, when greased with oil, occasionally absorbs air so rapidly, and produces so much heat

* In the ordinary lucifer-match (an invention since Davy's time) we have a striking illustration of the different temperatures required for various substances to enter into combustion. The phosphorus with which these lucifers are tipped becomes inflamed at a very low heat (60°), so that mere friction is sufficient to ignite it. This substance, in burning, produces heat sufficient to kindle the sulphur next to it; for this, as we have seen, enters into combustion at about 500°; and the sulphur again, in burning, raises the temperature sufficient to ignite the wood, which requires a heat of at least 1000° before it can be made to burn. Had the match been tipped with phosphorus alone, the phosphorous acid produced by the combustion would have incrusted the wood and prevented it inflaming. Before the use of phosphorus matches had become general, others were introduced, the tips of which were coated with a mixture of chlorate of potash and sulphur, and these had to be drawn forcibly through a piece of folded sand-paper, for this mixture requires a much higher heat in order to inflame it. Previous to the introduction of these, again, the common brimstone match was in general use. This, as is well known, was kindled by means of a spark in tinder—the tinder consisting of charred rag, and the spark, therefore, being merely a particle of charcoal at a red heat, while the ignition of the tinder itself was originally produced by the percussion of a piece of flint and steel, which evolved so much heat that small splinters of the metal were fused by it and fell upon the tinder in a red-hot state.

during the process, that spontaneous combustion frequently occurs from this cause. The same effect sometimes arises from *hay* being stacked before being perfectly dry; the moisture sets up a kind of fermentation in the interior of the stack, and this evolves so much heat that the temperature becomes raised to the point required for the material to enter into rapid combination with the atmosphere, so that spontaneous combustion is the result.

Again, there are certain mixtures of gases which are explosible at a red heat, while others cannot be made to enter into combustion at that temperature, but require the presence of flame in order to fire them. *Carburetted hydrogen* (*coal gas*), *sulphuretted hydrogen*, and *carbonic oxide*, can be made to inflame in air by red-hot iron or charcoal; and a mixture of *oxygen* and *hydrogen* gases can be exploded by a red heat visible in daylight, whereas a dull red heat only causes the two gases to combine silently without detonation. *Fire-damp*, however, (which is light carburetted-hydrogen gas, and the same as that which rises from stagnant pools on disturbing the mud at the bottom), cannot be inflamed by the strongest red heat; so that a fire made of charcoal, that will burn without flame, may be blown up to whiteness without exploding a mixture of this gas with air. A piece of iron also, at the highest degree of red heat, and even at an ordinary white heat, does not inflame an explosive mixture of *fire-damp*, but when brought to its *highest point of white* heat, iron immediately causes the fire-damp to combine with the air with a violent detonation.

The knowledge of this fact, which we owe to the researches of Davy himself, was of immense importance in the construction of the safety-lamp, and, once discovered, it was treasured in the brain for after use, for the preservation of life and the mitigation of suffering.

Again, there are some substances which are so readily inflammable that they take light even at the approach of flame. These bodies consist of highly vaporizable liquids, such as *alcohol*, *ether*, *naphtha*, *sulphuret of carbon*, *oil of turpentine*, &c. From the tendency of these combustible liquids to pass into vapour, the surrounding atmosphere (immediately on opening any vessels containing them) becomes charged with their fumes, so that an almost explosive mixture is formed with the air; and as this extends to some distance from the liquid itself, the approach of a lighted body instantaneously causes the whole volume of vapour to pass into one sheet of flame—an effect which is occasionally attended with the most disastrous results.

On the other hand, some combustible liquids require their temperatures to be highly raised before they can be inflamed; such is the case with the common fixed oils—as lamp-oil, and others. For this purpose a cotton wick is usually employed in burning them, so that, by the capillary attraction of the fibres, a small portion of the liquid may be raised above the level of the rest, and the oil thus be brought into connexion with the flame by minute quantities at a time; the consequence being that, as each small portion of the liquid is heated, it is converted into vapour, or gas—and this, by the high temperature maintained by the burning wick, is made to enter into combustion with the surrounding air, and so to be continually inflamed above it. Any porous substance which is a bad conductor of heat (such as Bath-brick or sandstone), will, if cut to a fine edge, answer all the purposes of the ordinary cotton lamp-wick; for if a light be applied to this, so as to raise its temperature sufficient to convert into gas the film of oil at the summit, the fluid will be readily inflamed, and continue burning until such an incrustation of charcoal ensues at the tip as to prevent the oil being heated any longer by the flame.

Further, some substances cannot be made to burn at ordinary temperatures in the open air, though, on being confined in a vessel of oxygen gas, they readily enter into combustion when their temperature is raised. This is the case, as we have seen, with iron, and some of the other metals.

The next problem to be resolved was, Whence come the light and heat that are emitted during the process of combustion?

"All cases of combination with oxygen," mused the youth, "such as the rotting of wood, and the gradual rusting of metals in the open air, are, probably, attended with the evolution of heat; but in such instances the process is so slow, that the heat evolved is unobserved, and dissipated without accumulation. When the combination, however, takes place in a shorter time, as in the production of vinegar, the heat becomes proportionately sensible; and when the combination with the oxygen is so rapid that the whole of the heat is evolved in a much more limited period, as during combustion, the increase of temperature is rendered considerably more intense. A pound of charcoal, for instance, combining with oxygen in the process of respiration, gives off the same amount of heat as it does when in a state of ignition, and takes up precisely the same quantity of the gas. In the one case, however, the combination is spread over 30 hours, whereas in the other it occupies but as many minutes."

Humphry reflected for a long time as to the origin of the light and heat evolved during the burning of substances.

"Are the light and heat," said he to himself, "originally imprisoned, as it were, in the combustible, and set free during the burning of it?

or are they merely the result of the rapid and energetic combination of the oxygen of the air with the burning substance?"

The former assumption the boy knew to be Lavoisier's theory of the subject, but such an explanation appeared to him to be inconsistent with the facts.

The *products of combustion* are not always the same. In some cases they consist of *gases*, as in the burning of Charcoal and Sulphur, &c.; in others, *liquids* are produced, as by the combustion of oxygen and hydrogen gases, the product in that case being merely water; while in others, again, a *solid* product is the result—as when phosphorus is burnt a white solid, called "phosphorous acid," being then formed: and so with zinc, the combustion of which produces a solid white rust, or oxide.

"Now, if the heat evolved during combustion," thought Humphry, "proceeds from the liberation of the *latent* caloric, or that which previously existed in the substances in an *insensible* state, it would follow that such heat should be given off only when the combustibles pass from a *rarer* to a *denser* form; as, for instance, when water is produced by the burning of its two constituent gases, or when the oxygen of the atmosphere becomes fixed in some solid product, as in the oxides of zinc or mercury.

"But by combustion," the boy went on, "many solid bodies are converted into gases; and in such cases, according to Lavoisier's theory, instead of heat being evolved, it should be *absorbed,* and positive *cold* produced by the process of burning.

"This, however, is not the case," added Humphry. "The explosion of *Gunpowder*, for example, is attended by immense heat, and yet the ingredients composing it, in passing from the solid to the gaseous state, expand some hundred-fold, having their volume increased, it is said, no less than 250 times. So, again, the gas called *Protoxide of Chlorine,* at the instant of decomposition evolves light and heat with explosive violence, and yet it is known to become one-fifth greater in volume afterwards. The oily substance, too, called *Chloride of Nitrogen,* on being made to enter into combustion, is resolved into its elements with tremendous force of inflammation, expanding into more than 600 times its bulk: so that, according to Lavoisier's theory, a prodigious degree of cold ought to be produced by such an expansion, whereas light and heat are evolved by it."

That the heat of combustion is due rather to intense chemical action going on at such times, Humphry made many experiments to prove.

First, he generated some *Chlorine,* or green gas.*

* Chlorine gas was called "*oxy-muriatic acid*" when Davy was a boy, from being supposed to be a compound of *oxygen* and *muriatic acid gas.* Davy, however, afterwards proved that this same

This he did by mixing in a retort some common salt with a little black oxide manganese, and some sulphuric acid and water. The gas which came over was of a greenish-yellow colour, and had a pungent, disagreeable smell, exciting cough and great irritation in the lungs when inhaled. Having collected some of this gas over warm water in a receiver, with a stop-cock at the top, the boy took a retort which had another stop-cock fitted to the end of it, and having introduced into this some copper-leaf, he screwed the retort on to the plate of his air-pump, and proceeded to exhaust it of air as perfectly as he could. This done, he screwed the stop-cock of the retort on to that of the receiver in which he had collected the gas; then, turning on both cocks, the chlorine rushed up into the retort, and the metal immediately became spontaneously ignited by it, and burnt in the gas with considerable energy.

The experiment was then repeated with a little powdered antimony, and the same vivid combustion ensued.

Now these Humphry knew to be cases of mere *chemical affinity*. The chlorine gas had a strong tendency to combine with the metals employed, and as these were used in the best form for promoting

oxy-muriatic acid contained no oxygen whatever, and was rather an elementary substance, being incapable of being resolved into any two other bodies.

the combination, the union of the gas with the copper and antimony was so rapid and energetic, that combustion was the consequence.*

Next, the lad took some *Sulphur*, and in this he heated some shavings of iron in a close vessel, when the metal, in a short time, was seen to become intensely ignited, and to burn, as it were, in the vapour of the sulphur. This was most curious, for sulphur he had never thought to be a supporter of combustion.

Further, Humphry heated some platinum and tinfoil, and at the moment when the two metals fused into one mass they became, to his astonishment, vividly ignited.

Nor was this all: the boy slacked some recently-burnt lime in a dark place, and found that, when the water was thrown upon it, the heat rose to upwards of 500°, while a faint light was emitted.

Another substance, discovered since the date of the above experiments, affords a striking illustration of the heat produced by energetic chemical action. This is a peculiar liquid called *Peroxide of Hydrogen* (see p. 264), consisting merely of water combined with an extra quantity of oxygen. So readily decomposible is this fluid, that at the heat of boiling water evolutions of gas are produced with

* A piece of blotting-paper dipped in *oil of turpentine*, and introduced into a jar of *chlorine gas*, immediately becomes inflamed.

such violence as to cause an explosion; and almost all the metals, when in a state of minute division, resolve it rapidly into its elements. The *peroxides* of lead, mercury, gold, platinum, &c., act on the liquid with surprising energy, the decomposition of it being complete and instantaneous upon dropping those substances into the liquid; for oxygen gas is then given off with such force as to produce a detonation, while the temperature becomes so intense that the glass tube in which the experiment is conducted grows suddenly red hot.

Subsequently, Humphry amused himself by mixing a little *Chlorate of Potash*, about the size of a pea, with the same quantity of *loaf sugar*, having previously reduced each to powder. Then he placed the mixture on a piece of tile, and, dipping a glass rod into a bottle of strong *Oil of Vitriol*, let the acid drop from the rod upon the powdered Chlorate and sugar, when they were instantly kindled, and burnt with a red and blue flame. For the Vitriol immediately decomposed the Chlorate of Potash, and so produced heat enough to ignite the materials; while the oxygen given out from the Chlorate maintained the sugar in a state of vivid combustion. A little *Camphor*, mixed with *Chlorate of Potash*, and touched with a drop of *Oil of Vitriol*, may be made to inflame in the same manner. A like effect is also produced when the *Chlorate* is mixed with *Spirits of Wine*.

After this, the lad placed a small piece of *Phosphorus*, and a few grains of *Chlorate of Potash*, at the bottom of a thin glass vessel, and then poured gently upon them some *hot* water. The heat of the water was sufficient to inflame the Phosphorus, while the oxygen evolved from the Chlorate of Potash in connexion with it tended to keep up the combustion; so that the two burnt with a vivid and pleasing light under the water.

Now Humphry knew that the reason of these effects was, that the Chlorate of Potash contains a large quantity of oxygen, which, having a strong tendency to combine with the combustibles, enters rapidly and energetically into union with them immediately their temperatures are elevated, and so gives rise to the phenomena of heat and light which are evolved during the combustion.

The same result is produced by *Nitre* in ordinary gunpowder, for this also contains a large quantity of oxygen gas, which serves to inflame the small particles of charcoal that are mixed with it, while the sulphur—which forms the other ingredient—being inflammable at a low temperature, renders the gunpowder capable of being united by a mere spark.

Oxygen thus appeared to Humphry to be the main "supporter of combustion," while the body burnt seemed to be the "combustible."

But Humphry had seen that bodies burnt in

Chlorine gas as well as in oxygen: this, therefore, was another "supporter of combustion." The same effect, again, he had found to be produced in the vapour of *sulphur*. Sulphur, however, was a "*combustible* body;" so that, in this instance, the same substance was both a combustible and a supporter of combustion.

The division of all bodies, therefore, into these two classes, as propounded by the French chemists, appeared to have no foundation in nature.

Nevertheless, Humphry was determined to put the matter to the test of experiment, and to see whether the light and heat evolved during combustion proceeded from the combustible itself, or from the combination of it with the air during the burning.

Accordingly, the lad inflamed a jet of hydrogen gas in a vessel of oxygen, when the light and heat certainly appeared to proceed from the jet of *hydrogen*, while the oxygen seemed to act merely as the *supporter* of the combustion.

On reversing the experiment, however, and causing the oxygen gas to issue from the jet, Humphry found that he could inflame it in a vessel of hydrogen, and that then the light and heat seemed to be evolved from the burning *oxygen*, while the hydrogen appeared only to keep it inflamed.

It was evident, therefore, from the last experiment, that even oxygen itself might be ranked among the *combustibles*, and hydrogen be considered as a *supporter of combustion;* but Humphry now saw that the real truth of the matter was, that the heat and light evolved during combustion came from *neither one substance nor the other*, but arose simply from the rapid and energetic chemical union of the *two:* for even two metals, at the moment of their union, evolve heat and light, as shown in the experiment of the fusion of platinum with tin-foil.

Combustion, therefore, is simply the consequence of the *rapid* chemical action of one body upon another; and the reason why it is necessary to elevate the temperatures of certain bodies before they can be inflamed, is merely because *heat* promotes the chemical action of substances upon each other.

CHAPTER XI.

HUMPHRY AND HIS "WONDERFUL LAMP."

HUMPHRY found it impossible to quit the subject of Combustion without some inquiry as to the nature of flame.

"What," said he to himself, "are those brilliant sheets of light that dart from burning substances? And why is it that certain bodies burn with the evolution of flame, and that others are merely capable of being rendered incandescent at the highest heat?"

Now the boy had before reflected upon the production of *heat* by the *slow combination* of oxygen with certain combustible substances, so he immediately passed to the consideration of the production of *light* by the same means.

He knew well that a stick of phosphorus always appears luminous in the dark, and that lines of fire can be written with it on a wall: the reason of this being simply that the air combines with it *slow-*

ly at ordinary temperatures. Again, the lad was aware that decayed wood emits a faint light, which is visible by night, the light being due to the same cause, viz. the *slow* combustion which is continually going on in it; for chemists have discovered that the rotting vegetable substance is constantly absorbing oxygen from the atmosphere, and evolving carbonic acid gas—the same as if it were really burning—though at a *less rapid* rate. Moreover, the decay of many animal substances, Humphry had read, is attended with like phenomena—the flesh of many fresh and saltwater fish becoming luminous previous to putrefaction.

But, in all such cases, the light emitted is more like a halo, or feeble *glow*, than the character of *flame;* or, rather, it seems as if the substance had become *incandescent in the cold*, and acquired the property of ignition at ordinary temperatures, so that it was capable of giving out light without being sensibly heated.*

Humphry had noticed, too, that a green wax taper—the colour of which he knew to be produced

* A few *flowers* have also the property of emitting light at ordinary temperatures. Among these may be cited the *tube-rose*, *nasturtium*, and *marigold*, which occasionally give out flashes of light on a warm summer's evening. This, probably, arises from the combination of the oxygen of the atmosphere with the vapour of the volatile oils upon which the perfumes of flowers are known to depend. Again, other substances emit light during the act of *crystallization*. This phenomenon is most dis-

by "verdigris" (acetate of copper)—on being lighted and blown out shortly afterwards, will continue glowing in the wick, or burning without flame, until the whole of the taper be consumed.

Now this, the boy was well aware, was another case of combustion, going on at a temperature *below* that of flame, though it was a state of continuous incandescence, requiring a higher heat for its production than the phosphorescence of decaying vegetable and animal matter.

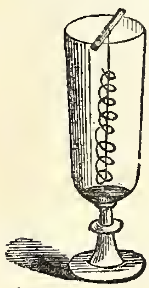
Having thought the matter well over for some little time, the boy-Chemist eventually conceived that it might be possible, by some such means, to produce a lamp which would burn continuously, and give light, without flame; and this he imagined might be found of great service in the coal-mines, since the fire-damp was not explosible at the highest *red heat*, and required positive *flame* to cause it to enter into combustion.

In the case of the glowing wick of a green taper, the youth saw that it was necessary for the wick itself to be made red hot before the ignition

tinctly observed during the gradual deposit of arsenious acid, when dissolved in hot hydrochloric acid (spirits of salts). In a dark place each crystal, as it is formed, may be seen to emit a spark of light; and on shaking the flask, so many crystals are sometimes suddenly produced, that vivid flashes become perceptible. The cause of this phenomenon is probably dependent on the fixation of oxygen by the arsenic at the moment of precipitation.

could be maintained; and he concluded that it was merely the incandescence of the wick which caused the gases given off from the taper to combine with the air, and so to keep it continually red hot. It struck him, therefore, that if he were to use some combustible liquid that was highly vaporisable, like ether, and to suspend above this a spiral coil of fine platinum wire, which had been previously heated to redness, the same continuous state of ignition might be made to go on, and that in a much simpler manner.

Accordingly, Humphry procured a tall ale-glass, and having poured into it a tea-spoonful of ether,



he suspended within it a coil of platinum-wire, which had been made red hot in the flame of a spirit-lamp.

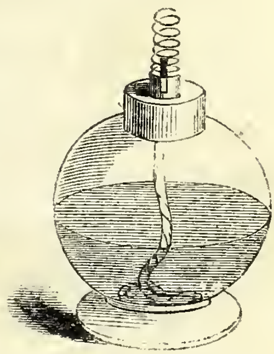
The arrangement of the little apparatus is represented in the annexed engraving.

Immediately the red-hot coil was placed in the vapour from the liquid, the excited boy was overjoyed to see it glow with a bright red heat. He stood watching it for a long time, and was rejoiced to find that there was not the least diminution of the incandescence till the whole of the liquid had disappeared, and the vapour been made by the heat of the wire to combine with the surrounding air.

Still it struck Humphry that a more convenient

HUMPHRY'S FIRST ATTEMPT AT THE SAFETY LAMP.—Page 291.

mode of attaining the same end might be devised; so he took an ordinary spirit-lamp (for spirits of wine he was aware had the same tendency to give off vapour as the liquid he had previously employed), and wound a coil of fine platinum wire round the wick — thus. Then, having lighted the lamp, he suffered it to burn a few seconds, after which he put an extinguisher over the flame, and instantaneously removed it. The consequence was, that the coil retained heat enough to carry on the *slow combustion* of the vapour from the spirit, so that the ignition was kept up, and the wire continued glowing, till the whole of the spirit had evaporated from the lamp.



Overjoyed at the discovery he had made, Humphry hastened to exhibit his lamp without a flame to Mr. Borlase and Mrs. Foxell, and his old friend Mr. Tonkin: and as he did so, the boy descanted fervently upon the superiority of such a means of obtaining light in coal-mines over the "*steel-mills*" which were then used for the purpose.

Mrs. Foxell was as pleased as the boy himself at what she considered the successful termination of his labours; and when Humphry ran over to her the long train of investigation he had pursued in order to arrive at the object, she was warm in her praises of his perseverance and genius, and assured him that, by such patient inquiry, he must ultimately gain the honours and the universal esteem which he so much desired.

Mr. Borlase was surprised at the talent of his young pupil, and went with him to Mr. Tonkin to talk over the matter; and when Humphry's foster-father saw what he had achieved, and was informed of the benevolent spirit which had stirred him to the discovery, the old gentleman hugged the lad to him, and told him he was well repaid for all the care and affection he had bestowed upon him.

When, however, the first impressions had subsided, and Humphry's exultation at the discovery he had made had been toned down by continually reflecting upon the subject, he began to think his little safety-lamp might be much improved if he could only increase the light from it. In its present form he thought it would be available merely in such cases as the steel-mill was used, viz. to explore those mines which were *known* to be charged with fire-damp. The miners, nevertheless, needed some light at their work, and if candles or lanterns were employed, the flame would be sure to ignite any fire-damp that might accidentally become mixed with the atmosphere, and so to cause the whole to explode.

What was required, therefore, was a light which would be as bright as those the miners employed at their work, but which would, at the same time, be incapable of inflaming the explosive gases evolved from the coals.

Such a light Humphry knew could be obtained only from flame itself, for he was now satisfied that it was impossible for any one to see to work by the rays from a red-hot wire. Still the difficulty was, that the presence of flame would be sure to cause the fire-damp to explode whenever it became mixed with the air in the mines, and it was impossible to make a lamp burn without air.

For a time the difficulties involved in the construction of such a lamp appeared to the lad to be insurmountable. At length, however, nothing daunted, he set to work to discover the nature of flame itself, and so to find out what conditions were necessary for the production and maintenance of it.

"*Flame*," said Humphry, while reflecting upon the subject, "may be regarded merely as *a sheet, or film, of gas, in a high state of ignition.* The temperature of flame is always very intense, since it will ignite substances that cannot be lighted, even with the highest heat of incandescence. The *light*, however, emitted by different flames is by no means equally vivid, since there are gases which burn with the production of a flame so feeble as to be scarcely visible in broad daylight."

Accordingly it struck the boy, that the best way to proceed would be to produce a feeble light first, and then to ascertain by what means he could increase the brilliance of it. So Humphry made a large bladder full of hydrogen gas, and then another bladder of oxygen, and proceeded to burn the gases together by means of two blow-pipes.

The flame produced was of a very faint blue colour, and though the boy closed the shutters, he could barely see to read by the light, and yet the heat of it was almost as intense as any that could be artificially generated;* for, on holding a platinum wire in the flame, it immediately became white hot, and the light was considerably augmented.

"So, then," cried Humphry, "the light emitted by a flame seems to be increased by solid substances introduced into it, and ignited by it."

This set the boy wondering what would be the effect if he were to cause some fine dust to pass continually through the flame, and whether the brightness of the light would be as much increased then as it was when the platinum wire was introduced into it.

The idea had no sooner struck him than he ran down to the shop, and procuring a little magnesia

* The blue colour of the oxy-hydrogen flame is due, probably, to the particles of water formed by the combustion of the two gases.

in fine powder, proceeded to sift this into the flame produced by the oxygen and hydrogen gases.

The result was almost magical.

No sooner did the fine white particles fall into the flame, than the light was changed from a faint blue into a brilliant white; while the little solid specks shone like so many gem-points in the sunshine, producing a glare that it pained the eyes to look at, and that instantly lighted up the little dark chamber almost with the vividness of daylight.

"It *is* as I expected!" shouted Humphry, as he gazed with admiration at the beautiful white light; "the luminosity of a flame depends chiefly upon the particles of *solid* matter diffused through it, and rendered incandescent by the burning gases. The flame of a candle or oil-lamp," the boy continued, "owes its brightness merely to the same cause; for there the oil, or grease, is converted into gas by the heat of the wick, and this gas consists chiefly of carburetted hydrogen—that is to say, of charcoal and hydrogen combined together: so that in burning, the hydrogen unites with the oxygen of the air and forms water, while the charcoal is set free, and passes up through the flame in the form of very minute particles, which being burnt there, and so rendered nearly white hot, cause the light to shine with great vividness."

To prove that the light of an ordinary candle, or oil-lamp, is due merely to the brilliancy of the incandescent particles of charcoal continually passing through the flame, the lad was not satisfied merely with holding a burning candle against the ceiling, and so causing the unburnt charcoal to be deposited upon it in the form of "lamp-black," as it is called; but he passed some hydrogen gas through a small reservoir of naphtha, and found that the brilliancy of the light was greatly increased by it: for, the naphtha being merely a liquid form of charcoal and hydrogen in combination, the gas, on traversing the fluid, took up a certain portion of the naphtha in vapour, and this being very rich in charcoal, was the cause of the increased illuminating power given to the flame.

The same principle has been applied since Humphry's time to the production of some of the most vivid of our artificial lights. The "Drummond light," for instance—which consists merely of a jet of oxygen and hydrogen gases projected against a cylinder of lime—owes its intense brilliancy solely to the particles of lime that are rendered white hot by the flame of the burning gases; and that the lime passes off in vapour is proved by the fact, that, during the combustion, the roof of the lantern becomes covered with the sublimed particles.

Again, the brilliancy of the electric light itself is known to arise from the particles of white-hot charcoal that pass over in vapour from one pole of the battery to the other; for it is found that the charcoal point in connexion with the *positive pole* becomes decreased and burnt into a cavity, while that in connexion with the *negative pole* is proportionately increased, having a small knob or protuberance of charcoal deposited upon it: so that, strange as it may appear, the brilliancy of the flame of a common tallow-candle depends upon the same cause as that of the electric light itself. In the one case, however, the combustion being imperfect, the points of charcoal are less vividly ignited; whereas in the other, the heat being the most intense that can be produced by artificial means, the incandescence is proportionately higher, and the brilliancy of the light, therefore, increased to the greatest point. In a word, the particles of charcoal in the flame of a candle are only at an *orange* heat, whereas those in the voltaic flame are at the highest *white* heat that art can generate.

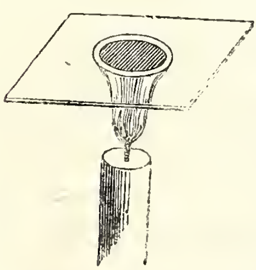
Accordingly, *artificial light* would appear to be due solely to *artificial heat*, and the illuminating power of even flame itself to depend upon the incandescence of the particles of solid matter diffused through the burning gases.

Humphry's next object was to discover whether flame really consisted, as he before said, of a sheet or film of gas in a state of combustion.

"The flame of a common candle," he mused, "appears to be a solid cone of luminous matter. *Is* it, however, really alight in the middle?" the boy mentally inquired; "or is it burning at the outside only, so that the thin film of white-hot vapour incloses a portion of combustible matter within it, which cannot burn for want of air? How can I ascertain this?"

Humphry thought for a while, and then it struck him, that if he were to place a piece of thin glass upon the flame itself, so as to press it down as it were, he could then see whether or not it were alight in the middle; for if it were alight round the edge only, he would behold through the glass a bright ring of flame, with a dark spot in the centre, indicating the portion where the combustion was not going on.

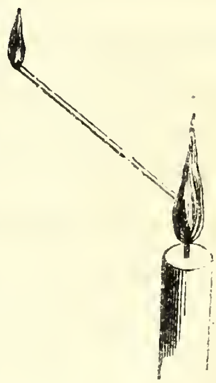
The experiment was soon tried, and the result proved as Humphry had anticipated. A luminous circle was seen through the glass, at the point where the flame touched the surface, and in the



centre of this there was a dark spot, like a black wafer, showing where the decomposed charcoal gas existed in the interior of the flame in an unburnt state. The appearance, however, is represented in the subjoined illustration. Indeed Humphry perceived, that as air was necessary for combustion, and it was impossible for the atmosphere to get to the interior of the flame, the outside only of the cone of combustible gases, evolved from the decomposed tallow, could be alight; while the vapour in the centre could be burnt merely as it passed off into the air at the upper part of the flame.

The next step was to see whether the interior dark part of the flame really consisted of the same inflammable gases as were in a state of combustion at the exterior, or surface of it.

Accordingly, Humphry placed a small glass tube within the centre of the flame from an ordinary candle, and found that the unburnt gas from the interior readily made its way up the tube, and escaped at the top of it, and that on applying a light to this it was immediately ignited; so that two flames were thus produced from one candle, as here shown.



Another proof that the gases in the interior of the flame were not in a state of combustion was afforded by lighting some spirits of wine in a large spoon; for Humphry then found that he could introduce some grains of gunpowder, and even some pieces of phosphorus, by means of a tube, into the middle of the flame, without igniting them.

Humphry, moreover, could now see that the reason why the blow-pipe so much increased the heat of an ordinary flame is simply because a current of air is made by such means to traverse the interior part of it, so that the combustion being rendered more perfect, the temperature, of course, becomes proportionately higher.

Again, the wick of the "Argand Lamp" is constructed circular, so that a current of air may be supplied to the interior of the flame; and hence the superior brilliancy of this kind of burner. Table-lamps are now generally made upon the same principle, and so, indeed, are the gas-burners in shops. Sometimes, however, a jet is used, with the holes so arranged as to spread the gas into a thin wide sheet, and thus allow the air to act upon a large surface of combustible matter at each side. These are called "*bat's wing*" and "*fish-tail*" burners, &c., according to the shape of the flat broad flames produced by them.

The next point in the inquiry was to discover what would be the effect of cooling down a flame, since it was evident that it required a *very high temperature for its existence.*

Humphry was well aware that, by projecting a current of cold air upon substances in a state of combustion, the flames were generally extinguished. Still he wished to see whether it was not possible to lower the temperature of a flame by some other means.

Accordingly he procured a piece of wax-candle, and proceeded to pull out all the wick, except one thread, so that when it was lighted the flame from it should be as small as possible. Then the boy made a little ring of iron wire, about the eighth of an inch in diameter, and this he affixed to a wooden handle. Passing the wire ring over the lighted wick he found, that on bringing it a little below the flame the light was immediately extinguished, for the metal, being a good conductor of caloric, served to carry off the heat which was necessary for the maintenance of the flame.

It then struck Humphry that the pins which housewives stuck in rushlights that they wished to be extinguished at a certain time, acted merely upon the same principle—the metal carrying off the heat, and so lowering the temperature requisite for the existence of the light.

The youth thought for a long time as to whether he could avail himself of this principle in any way for the construction of his safety-lamp, for, as he had now discovered that it was possible to extinguish flame merely by reducing its temperature—and that a piece of wire, placed in connexion with it, did this most effectually—he fancied he might take advantage of some such means for preventing the passage of flame to fire-damp. But though he racked his brain long he could hit upon no plan for accomplishing his object. So he contented himself with merely making a memorandum of the fact in his note-book, saying to himself, that he knew it would prove serviceable some day—and then passed on to another part of his inquiry.

Fire-damp, he was well aware, is explosible only when mixed with the atmosphere; for the air is necessary for the combustion of all substances, and explosion, as before observed, is merely the result of *instantaneous combustion.* Still, certain liquids, Humphry knew, are attracted by the sides of fine tubes, so that the fluid in which they are immersed is maintained within them above the level of that without. He knew, too, that by the same principle a certain quantity of water might be retained in a fine sieve without running through the holes; and that a vessel full of small holes might, for the like reason, be immersed to a certain depth in water without sinking, or any of the liquid entering it.

So the lad was anxious to see what would be the effect of fine tubes upon gases, and whether, upon passing an explosive mixture of carburetted hydrogen and air along a narrow glass pipe, the flame would pass down it, or be arrested in its progress.

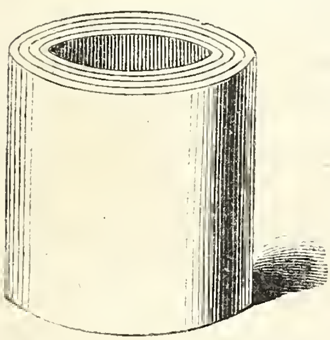
Accordingly, having prepared some carburetted hydrogen gas, and mixed it with eight parts of air —for these proportions he had found to be the most explosive—he passed the mixture along a glass tube, the bore of which was only $\frac{1}{8}$th of an inch in diameter, and discovered, on lighting the gas that issued from the end of it, that the flame, instead of travelling down the narrow channel, and being instantly communicated to the whole of the explosive mixture, remained stationary at the orifice of the tube, where the gases burnt as slowly and quietly as with an ordinary candle.

Humphry was half-bewildered with joy at the discovery he had made. Fire-damp he had now ascertained was not explosible within narrow tubes, and instantly a hundred and one plans flashed across his mind for rendering the fact serviceable to those engaged in the coal-mines.

Still there was much to work out. It was necessary to know through how large a tube flame *was* capable of being transmitted; so he procured another glass pipe, the bore of which was a quarter of an inch in diameter, or double that of the one he had first employed, and passing the same explosive mixture along it, he found that, on lighting the gases at the end of this, the flame no longer remained stationary at the orifice, but travelled slowly down the channel, taking more than a second before it reached the other end, though the tube itself was only a foot long.

Then pursuing the same course of experiments, Humphry subsequently discovered that by diminishing the diameter of the tube he could shorten the length of it without any danger of the flame travelling along it, and so causing the gases without to explode. Moreover, the lad ascertained that when fine metal tubes were substituted for glass ones, the security was even more perfect.

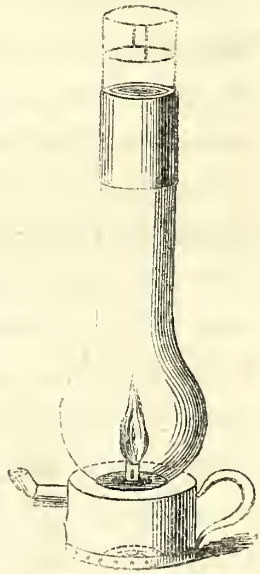
To insure greater safety, however, by making the channel through which the explosive gases passed as fine as possible, he ultimately inserted some short pieces of metal tubing, one within the other; so



that the bores being of different diameters, they formed a series of broad concentric rings, each enclosing another, and having a *fine channel* between them—thus.

These Humphry proved to be perfectly secure against all explosion, and then proceeded to fix one set at the bottom of a lamp, and another at the top of a glass chimney that was made to fit air-tight round the flame. The concentric tubes at the bottom were for the supply of air to the light, and those at the top for the issue of the smoke; so that thus, if any fire-damp were present in the mine, and entered with the atmosphere through the air-tubes at the bottom, the flame would not be communicated to the explosive gases outside the lamp—and thus the safety of the miner would be thoroughly ensured.

For rendering the arrangement adopted more intelligible, a design of Davy's first Safety-Lamp is here given.



The principle upon which this lamp depended for its security had been so carefully worked out that it scarcely required testing. To assure himself, however, of its efficacy, the boy immersed the lamp in the most explosive mixture of carburetted hydrogen and air that he could possibly form, and was well repaid for all his labours by seeing that the flame was incapable of being transmitted to the combustible gases without; so that, upon their entering the lamp, the light itself was extinguished. In a word, he found that his lamp was "absolutely safe," and that the fire-damp had been disarmed by him of its terrors.

Humphry's friends were as delighted as the boy himself at the successful termination of his labours. Mrs. Foxell, who had, in the first instance, encouraged him to proceed, was, perhaps, the most gratified of all; nor did she refrain from lecturing her brother, Mr. Borlase, upon his previous want of faith in the accomplishment of the result, telling him that it was cruel, where so many lives were at stake, to damp the ardour of any one who could believe in the possibility of rendering them secure for the future.

Mr. Borlase was sufficiently generous to confess his error, and frankly acknowledged that he never thought Humphry would be able to accomplish half as much as he had.

The boy's old friend, Mr. Tonkin, too, felt prouder than ever of his foster-son, when he saw the lad test the powers of the lamp in his presence; and the old gentleman made Humphry's heart swell again with the praises he heaped upon him, and the tears start to his eyes with the confession of the long love he had borne the boy.

At length, however, Mr. Tonkin said that he thought one improvement still was required, though how it was to be effected he must leave Humphry to find out, for it was more than he could manage. On the admission of the fire-damp into the lamp the light was extinguished. "This," the old gentleman observed, "appeared to be a great defect, for the extinction of the flame was a sure indication that danger surrounded those who carried the lamp; and to leave the miner in darkness at a time when immediate flight was necessary, struck him as being a serious drawback to its utility. If Humphry, therefore," he said, "could, by some means or other, arrange it so that the light should continue burning, even in the presence of the fire-damp itself, the ingenuity of the apparatus would not only be much greater, but its value be considerably enhanced."

Humphry saw the force of Mr. Tonkin's objection, and it struck him that the defect was almost irremediable. He was, therefore, not a little vexed to find that an instrument which he had fancied perfect, was not altogether faultless.

The lad pondered over the matter for many days, and tried a number of experiments to overcome the difficulty which had been raised. It proved, however, beyond his powers; so, exhausted by his long study, and vexed at the idea of his comparative failure, Humphry, at length, dismissed the subject from his mind, and locked the safety-lamp in his cupboard, determined that it never should be made public until it was perfect in all its arrangements.

It was in vain that Mrs. Foxell urged him to make known the invention, even in an unfinished state; but the boy was firm in his resolve. "*Some day*," said he, "it shall be completed, and then the world may have it, and welcome; but as it is now, it is hardly worth either the giving or accepting, and no honours can come of it. When I know more," he added, "I can do better: nor do I intend, because I have been baffled in this my first project, to give over studying; for I find such delight in the perception of the new truths which are daily unfolded to me, that I would rather forego any source of pleasure than that which comes from scientific discovery."

It was many years before the Safety-Lamp was perfected; and when it was, the alteration was so slight, that it has been well observed—"The history of this elaborate inquiry affords a striking proof of the inability of the human mind to apprehend simplicities without a long process of previous complication."*

Humphry Davy, as we have narrated, had already discovered, while experimenting upon the inflaming of explosive gases in narrow tubes, that, provided he diminished the bore, he could shorten the length of them in a corresponding ratio. Now a sheet of wire-gauze, it is obvious, consists merely of a series of fine tubes, of very short lengths. It appears strange, therefore, that our hero was some time before he conceived the happy idea of constructing his lamp entirely of wire-gauze, instead of feeding it with air through narrow channels, or "safety canals," as he called them; for, as flame cannot be transmitted along small tubes, it is manifest that, on surrounding a lamp with a wire-gauze cylinder, or cage, the fire-damp, as it enters with the air, will burn within the cage itself, and the

* Dr. Paris's "Life of Sir Humphry Davy," p. 352.

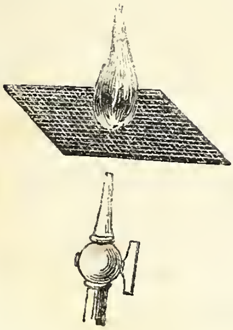
flame be incapable of passing through the small apertures in the gauze, and thus exploding the gas outside of it.

To render the action of wire-gauze in this respect more intelligible, a few of Humphry Davy's after-experiments may be cited in connexion with this part of the subject.

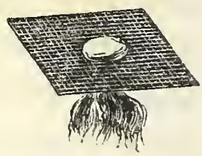
If a small piece of wire-gauze (say about 9 inches square, and having about 30 meshes to the square inch) be gradually brought down upon the flame of a candle, the flame itself will be cut off where it touches the gauze, and merely a dark spot be there observed, encircled by a ring of light, while the combustible matter of the flame will issue through the small apertures in the form of smoke; for during the passage of the burning gases through the metallic meshes they will be so far cooled down that the flame will be extinguished, and thus rendered incapable of traversing the gauze itself.

If, however, a lighted taper be held above the wire-gauze, the inflammable gas or smoke from the candle will be immediately rekindled, and the flame continue to burn then, both on the upper and under side of the tissue.

But the impermeability of metallic gauze to flame may be rendered still more evident, by placing a piece of fine wire web above a jet of gas previous to lighting it, when it will be found that, if a burning taper be held over the wire web, the gas will be kindled above it, and continue to burn upon the gauze itself, while the combustible matter beneath will remain unignited; for the metallic threads, being good conductors of heat, will so cool the flame as to prevent it passing through to the gas on the lower side.



Again, if a small piece of camphor be laid in the centre of a sheet of wire-gauze, and a light held beneath it, the vapour from the camphor, which is very inflammable, will be made to burn with a bright flame *downwards*—instead of upwards, as flames usually do—while the camphor itself will lie upon the upper side of the tissue in an uninflamed state.



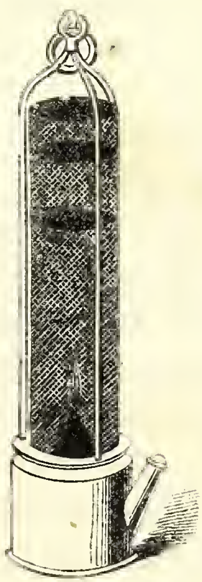
The power of metallic webbing thus to intercept or extinguish flame, depends simply *upon the cooling effect* it produces; so that as flame requires a high temperature for its existence, it is plain that it no sooner becomes cooled, by being passed through a good conductor of heat, than it is extinguished.

If, however, the meshes of the wire-gauze be not sufficiently small, or if the wire of the gauze itself becomes intensely heated, the flame will traverse it in either instance; because the cooling power is reduced, in the one case, by the largeness of the apertures, and in the other by the high temperature of the wire.

For the knowledge of these facts, we repeat, we are indebted to the after-investigations of Davy himself.

Now it is evident from the above experiments, that if a lamp be covered with a cylindrical cage of wire-gauze, no flame will be able to pass from the interior of the lamp to the exterior of it, in consequence of the cooling power of the metallic web encompassing it; so that, if the surrounding air be charged with an explosive gas, it will enter the lamp through the meshes of the web and burn within the cage, while that without will remain unkindled.

Such, then, is the principle of the "Safe-Lamp" as perfected by Davy, and which is here shown:



The safety of this lamp may be exhibited by immersing it in a large jar, at the bottom of which is a little Ether; for the vapour from this liquid, on mingling with the air, forms a highly inflammable atmosphere. On introducing the lamp into this, the flame first becomes enlarged and is then extinguished, while the whole of the cage remains filled with a lambent blue light. On withdrawing the lamp, however, and bringing it into the open air, the wick is suddenly rekindled, and the flame returns to its natural size and colour.

For perfect safety, it is necessary that the wire-gauze of these lamps should contain about 30 wires, or 900 apertures in every square inch, and that the heat of the wire itself should never rise above redness; for "if," as Davy said, "the iron wire become white hot, the lamp will be no longer safe. This, however," he adds, "need never happen in a colliery; for if a workman finds the temperature of the wire increasing rapidly in an explosive atmosphere, he can easily diminish the heat by turning his back upon the current, and keeping it from playing upon the gauze by means of his clothes."

Of this wonderful lamp it has been well said, "that it is a present from Philosophy to the Arts, and to the class of men farthest removed from the interests of science. We know of no discovery in which the admirer of Science and the lover of mankind have greater reason to congratulate one another. The discovery," adds the late Professor Playfair, "is in no degree the effect of accident; and chance, which comes in for so large a share in the credit of human inventions, has no claims on this, which is altogether the result of patient and enlightened research. The great use of an immediate and constant appeal to experiment cannot be better evinced than in this example. The result is as wonderful as it is important. An invisible and impalpable barrier, made effectual against a force the most violent and irresistible in its operations, and a power that, in its tremendous effects, seemed to emulate the lightning and the earthquake, confined within a narrow space, *and shut up in a net of the most slender texture;* these are facts which must excite a degree of wonder and astonishment, from which neither ignorance nor wisdom can defend the beholder. When to this we add the beneficial consequences, and the saving of the lives of men, and consider that the effects are to remain as long as coal continues to be dug from the bowels of the earth, it may fairly be said that there is hardly, in the whole compass of art or science, a single invention of which one would rather wish to be the author."*

It should be borne in mind, moreover, that Davy in the accomplishment of his noble task, not only did not seek, but positively rejected all pecuniary re-

* "Edinburgh Review," January, 1816.

ward; so that it becomes difficult which to admire the most—the benevolence which prompted him to undertake the long train of laborious investigations, the genius which carried him to so successful an issue, or the noble disinterestedness which bade him refuse to traffic in an invention that was destined to mitigate the sufferings of some of the poorest and least educated of his fellow-creatures.*

* "It will hereafter be scarcely credited," says Dr. Paris, "that an invention so eminently philosophic, and which could never have been derived but from the sterling treasury of science, should have been claimed in behalf of an enginewright of Killingworth colliery, of the name of Stephenson; *a person not even professing a knowledge of the elements of chemistry.*" The "enginewright" here sneered at for his ignorance, ultimately rose to be the great George Stephenson, the inventor of the locomotive. How would the fashionable physician speak of the quondam enginewright of Killingworth colliery now! Stephenson's lamp was formed on the principle of admitting the fire-damp by narrow tubes, and "in such small detached portions, that it would be consumed by combustion." The two lamps were, doubtlessly, distinct inventions, though Davy, in all justice, appears to be entitled to precedence—not only in point of date, but as regards the long chain of inductive reasoning concerning the nature of flame by which his result was arrived at.

CHAPTER XII.

HUMPHRY PRACTISES AS A SURGEON—ON HIMSELF.

Humphry by this time desired some little recreation. He had been at work for many weeks uninterruptedly—his days given to his profession, and his leisure, in the evenings, devoted to the prosecution of his scientific discoveries; and what with the exhaustion of continuous thought, and the vexation at his inability to perfect the lamp, from which he had such high hopes of honour, the lad felt incompetent to resume his labours until his mind, by diversion, had recovered somewhat of its ordinary elasticity.

Accordingly, he determined upon enjoying a day or two's fishing with his uncle Millett—for this was Humphry's favourite pastime throughout life; and the sport, his biographer tells us, "was alike his relief in toil and his solace in sorrow."*

* "Davy's passion for angling betrayed itself upon all occasions," says Dr. Paris; "whenever I had the honour of dining at his table, the conversation, however it might have commenced,

It was now spring, moreover, when the small streams, the youth knew, were in the best state for angling—turbid, in a slight degree, from the mild rains common in April and May; so Humphry, having arranged his tackle on the over-night, sallied forth the next morning to join his uncle at Marazion.

The lad's fishing costume was singular enough to claim some notice. It consisted of an entire suit of green—that colour being considered by him the most likely to elude the observation of the fish. The coat was half covered with lappets of the many pockets for holding the necessary tackle; and his hat (which was a round felt one, with a broad brim like a wagoner's), had been dyed of the same colour as his clothes by a pigment of his own composition; while round the hemispherical crown were coiled a series of fine lines, each term-

invariably ended on fishing; and when a brother of the angle happened to be present, you had the pleasure of hearing all his encounters with the finny tribe—how he had lured them by his treachery, and vanquished them by his perseverance. He would occasionally strike into a most eloquent and impassioned strain upon some subject which warmed his fancy; such, for example, as the beauties of mountain scenery: but before you could fully enjoy the prospect which his imagination had pictured, down he carried you into some sparkling stream, or rapid current, to flounder for the next half-hour with a hooked salmon. . . . Nothing irritated him so much as to find that his companions had caught more fish than himself, and if, during conversation, a brother fisherman surpassed him in the relation of his success, he betrayed similar impatience."

HUMPHRY EQUIPPED FOR A FISHING EXCURSION.—Page 319.

inating in some peculiarly-coloured artificial fly: so that the hat appeared somewhat like a clod of turf upon which so many bees and moths had settled. His legs, again, were encased in a huge pair of jack-boots, which, for the convenience of wading through the water, reached above his knees; indeed, as Macbeth says of the witches, "He looked not like an inhabitant o' the earth, and yet was on't."*

Thus equipped, Humphry, as we said, sallied forth, with the joints of his rod strapped together—like a small bundle of fagots—and resting on his shoulder, while at his back projected the wicker fish-basket, as if it were a huge cartouche-box. Over the other shoulder were slung the heavy jack-boots, and at his side ambled his favourite water-spaniel "Chloe," her long tail wagging as she stopped now and then to look up in her master's face, for she seemed to be as delighted as the boy himself at the anticipation of the sport that she knew was about to ensue.

The youth paused occasionally to fondle the knowing creature, for he had her since a pup—having begged the gift of her when she was taken from her mother, and about to be drowned with the rest of the litter as soon as born, and it was only by great care that he had been able to rear her, so that

* *See* Dr. Paris's description of Davy's ordinary fishing costume, p. 189.

the two were as attached to each other as any human friends could be; nor did Humphry treat her as a dumb animal, but spoke to her as though she understood every word he said: and, perhaps, in his heart, the boy (with his half-poetic and half-metaphysic theories) *believed* she did.*

It was late that evening before the couple returned from the day's sport, and then Chloe carried in her mouth a small basket containing a portion of the spoil, for Humphry's wicker knapsack was not capacious enough for the whole, as he and his uncle Millett—so runs the record—had caught no less than "seven dozen trout in the rivulet and mill-pond near the residence of the Rev. Mr. Giddy, in the parish of St. Earth."

Humphry's success at his sport had made him too light-hearted to feel the fatigues of the day, and although he was somewhat foot-sore from the long use of the heavy boots he now carried over his shoulder, the boy and Chloe jogged merrily past the tanneries at the extreme west of the town; for the dog knew as well as her master, by the leathery

* "This favourite dog is well remembered in Penzance," says Davy's brother. "My sister writes," he adds, "that 'on his first return from Bristol, after an absence of about twelve months, Chloe did not remember him, till he called her by name, and then she was in a transport of joy.' Her descendants are now numerous in the Mount's Bay, and prized for good qualities." Vol. i. p. 54.

smell that filled the air at that quarter, that they were not far from home *then;* and Humphry, as he patted the fond animal, promised her a good supper of fish for all that she had done that day.

As they passed down Market-Jew Street the oil-lamps and candles were being lighted in some of the little shops, and Humphry saw, as he looked towards the Town-Hall at the end of the street, that the sun had long since set, for the sky was grey with the thickening dusk, and the stars were beginning to peep out of the haze, one after another, through the darkening firmament.

At length the Town-Hall itself was reached, and the youth was telling Chloe that she should soon have her supper now, when suddenly a loud cry was heard. As the lad turned round towards the street that led to Madern Church to ascertain the cause of the noise, he beheld to his horror a huge dog, at full speed, hurrying in that direction, white with foam at the mouth, and followed by a mob of affrighted people, hooting and hallooing at its heels. Some of the men were armed with pikes, and others carried muskets, intent on the destruction of the rabid animal.

Humphry, with Chloe still by his side, was within a few paces of the furious creature. The boy saw in an instant that flight was impossible, and dreading lest his favourite dog should be attacked, he shouted

"Back! back!" to her in his most commanding tone. The order, however, was too late, for Chloe, being a little in advance of her master, had already attracted the notice of the infuriated brute, and Humphry saw her danger at a glance. In another moment his own dog would be seized by the rabid one, and the slightest graze from its teeth he knew would be sufficient to render Chloe's immediate destruction a matter of duty. It was no time for reflection, so the excited boy, eager to save the life of his favourite spaniel, rushed past her with his heavy fishing-rod raised high in the air, and ready to fell the dangerous brute to the earth.

Ere he could aim a blow, however, the hunted dog had fastened on Humphry's leg, and fixing his fangs in the flesh, inflicted a wound that made the lad shriek again with the suddenness of the pain.

The cry of her master brought Chloe instantly to the rescue, and dropping her basket of fish she sprang, yelping, towards the savage brute. Humphry knew the peril of the encounter, and finding the animal about to relax its hold of his flesh, he seized it by the neck and held its head firmly to the ground, while the townsfolk rushed immediately to the spot, and with their weapons soon put an end to all the danger.

"Tha bee'st bitten, Master Humphry," shouted Malachy Carteret, as he drew his adze from the head of the animal; "run tha to Dr. Borlase directly, and ha' the bite looked to, or tha life, poor boy, a'n't worth a dried pilchard."

Then came Jan Penberthy the miller—as white as plaster-cast in his working dress—and he, with a cluster of others behind, were anxious in their inquiries as to what was the nature of the wound, while each had some novel and different remedy to recommend.

Humphry, however, knew sufficient of his profession to be aware that it was no time for hesitation; so, while the eager throng crowded around him, he raised the leg of his trousers, and observing the marks of the animal's teeth in his flesh, he deliberately drew his knife from his pocket, and there, upon the spot, cut out the lacerated part without a wince.

This striking instance of the boy's intrepidity was hailed with wonder by the people about him, and one and all were loud in their praises of his courage and decision. Many who had known him from a child rushed up and shook him warmly by the hand, while others, who had been the companions of his father, declared he was Robert Davy's own son every inch of him—indeed all there had some encouraging word to say or some kindness to proffer.

Humphry, however, was too sick and faint from loss of blood to be able to listen to the remarks of those about him; so, having tied his handkerchief round the wound, he begged Malachy Carteret to help him home to Dr. Borlase's. And as the little carpenter curled the boy's arm about his neck Humphry limped along with Chloe at his side, who kept looking up sadly in his face, as if she was aware of all that had happened, while the boy exclaimed as he went, "Thank God I have saved your life, poor Chloe, even though it be at the expense of my own."

Following in the wake of Humphry and Malachy walked many of the crowd—one carrying the boy's fishing-rod, another his jack-boots, and another the basket of trout that Chloe had dropped in the road; and as they went along, they wondered among themselves whether Master Humphry would get the better of the bite; and some told curious country tales as to how the poison had remained in the blood for years afterwards, so that a person's life was never safe from it.

On reaching the surgery, Humphry found that Mr. Borlase had been called to visit a patient in the country that evening; so, being left to his own resources, he proceeded forthwith to apply some lunar caustic to the wound himself, and having done this, he begged Mrs. Foxell (who was frightened to tears at the dangerous accident he had met with) to make his excuses to her brother, the doctor, when he returned, for the poor boy told her he was anxious to reach his mother's house before the news of his having been bitten by a mad dog was carried home, so that he might lighten her alarms on his account.

Humphry, however, had barely taken leave of Mrs. Foxell before Mrs. Davy herself rushed into the surgery, half frantic with fear at what she had heard; and she no sooner caught sight of him than she fell upon his neck, and wept and laughed by turns, hysteric with the intensity of her emotion.

The boy endeavoured to assuage her, assuring her that from the promptness and vigour of the remedies he had applied there was little cause for alarm. But to no avail: the poor woman was satisfied her darling boy was doomed to the most frightful of all deaths sooner or later, saying, "that if she was deprived of him her cup of bitterness would be full indeed." Then the heavy privations she had already suffered in life rose again to her mind, and in the agony of her despair at the calamity which now threatened her she wrung her hands, and cried aloud to God to have mercy upon her.

Nor could she in any way be soothed until the lad told her it was necessary for him at such a time to remain in perfect quietude, and that the least excitement might develope the very symptoms which she dreaded.

This had the desired effect. Such was her love and care of the boy, that not another tear did she afterwards shed in his presence ; but, dismissing her own trials, she talked to him only of the subjects she knew he delighted in; and, when she had him removed to her own house, she sat by his bed, day after day and night after night, reading to him from works on the different sciences till his eyes were closed in sleep, and then the poor widow would fall upon her knees, and with her pent-up tears streaming in secret from her eyes, and her voice choked with her sobs, pray the Great Ruler of All to spare the only protector left her.

HUMPHRY'S MOTHER READING TO HIM DURING HIS ILLNESS.—Page 326.

CHAPTER XIII.

THE FIRST SUN-PICTURES.

HUMPHRY remained confined to his bed for many weeks, and every day his mother dreaded seeing some development of the symptoms which generally ensue from the bite of so rabid an animal; but the boy assured her, again and again, that, owing to the promptitude of the remedies he had applied, there was no cause for alarm.

While the youth was still a prisoner in his room, a gentleman came to lodge at the house, and Humphry, to his great delight, learnt, in a few days afterwards, that the new lodger was no less a person than Mr. Gregory Watt, son of the celebrated James Watt, the inventor of the present steam-engine.

It did not take long before the two became acquainted, and then Humphry ascertained that the young Mr. Watt had but recently quitted the University of Glasgow, and had been recommended by his physicians, owing to his declining state of health, to reside for some time in the West of England; hence the cause of his visit to Penzance.

Nor was Humphry long in discovering that the mind of his new friend was enriched beyond his age with science and literature, and that he possessed, like himself, a spirit devoted to the acquisition of knowledge, and soaring far above the little vanities and distinctions of the world. The two kindred spirits, therefore, soon contracted an intimacy of the warmest nature; and this ultimately ripened into a friendship which continued to the period of Mr. Watt's premature dissolution.

Mr. Gregory Watt felt not a little astonished, on being introduced to the son of his landlady, to find him shortly afterwards speaking upon subjects of metaphysics and poetry; for when Mr. Watt spoke to him of the courage he had displayed at the time of the accident in excising the wounded parts of his leg, Humphry confessed "that he had no belief in the existence of pain, whenever the energies of the mind were directed to counteract it."* "For," went on the boy, "in states of profound attention, all perception of external things fades from the mind; the clock in the room ticks, and we hear it not; persons enter the apartment, and their presence is unheeded by us. And if

* See Dr. Paris's "Life of Davy," p. 12.

by the intensity of the intellectual operations the senses can cease performing their functions in the one case, why not in the other? Martyrs at the stake have, while in deep prayer, held their hand unmoved in the flames, and who can say that the very fervour of their heavenly aspirations did not deprive them of all sense of pain for the time being?"

Mr. Gregory Watt, however, had but little taste for metaphysical discussions; and, smiling at Humphry's stoicism, sought to divert the conversation into a more congenial and practical channel.

The steam-engine that had been recently set up at the Wherry Mine by Mr. Watt's father became the theme of their converse; this soon led to comments on the theory upon which its powers depended, and then Humphry's companion was surprised to find that a youth, who had been brought up in an obscure town in Cornwall, was as well acquainted with the doctrine of "latent heat"—and, indeed, the whole science of caloric—as he himself, who had been reared, as it were, in a factory, where the workings of it were every day visible.

The new laws of combustion naturally followed as the next subject of discussion, when Humphry observed, "that he would undertake to demolish the French theory in half-an-hour;" and so saying, he rapidly ran over the experiments he had performed, to prove the falsity of Lavoisier's notions respecting the origin of heat during the burning of substances.*

The lad had now touched the true chord, and the interest of Mr. Watt becoming more excited, he conversed with young Davy upon his chemical pursuits, and was at once astonished and delighted at his sagacity; so that the couple—congenial in taste—already began to feel a growing friendship for each other.

Humphry had quitted his chamber, but was still confined to the house, from his inability to walk, when Mr. Watt—who had now known the youth long enough to be proud of his acquaintance—returned from his morning's stroll along the sea-shore, in company with two friends whom he had met in the town.

The gentlemen proved to be Mr. Josiah Wedgwood, the eminent potter of Staffordshire, and his brother Thomas, who was alike distinguished for his scientific abilities.

The learned potter was not long in Humphry's company before he discovered the high merits of the lad; nor was he a little pleased when he found that the young Cornish apothecary knew all about the pyrometer he had invented for measuring high

* See Dr. Paris's account of Davy's first interview with Gregory Watt, p. 35.

degrees of heat by the contraction of a ball of clay; and the old gentleman found considerable delight in explaining to the boy the various processes concerned in the manufacture of earthenware and porcelain, telling him anecdotes as to how Bernard Palissy — who was the first to discover the means of giving a glaze to the baked clay —had been reduced to such poverty by his experiments, that he was forced to burn the doors, and even the boards, of the house in which he lived, in order to get a supply of fuel for his furnaces; and how he afterwards amassed an immense fortune by the invention, and ultimately died in the French Bastille, a martyr to the Protestant creed, which he had espoused. Mr. Wedgwood added that, "When we eat our food we little think of the labour and privations that have been endured in order to give a glassy surface to the plates and dishes upon which it is served; for but few are aware that, previous to this invention, the ordinary earthenware articles were more like tiles than our present crockery."

Then Mr. Wedgwood talked with the youth about the rocks, inquiring whether he had ever noticed any of the finer species of clay in those parts, and was surprised to find how closely the boy had marked the changes in the soil; for Humphry told him "he had observed that the felspar in the granite decomposed long before either the mica or the quartz, and that it was chiefly by the action of the atmosphere upon this same felspar that the huge granite rocks became disintegrated, or broken up; and that, as the felspar consisted principally of clay in the purest form, he fancied that some advantage might be taken of this in producing a finer species of porcelain than had yet been manufactured in this country."

The old gentleman thanked Humphry for his suggestion, and warmly praised him for his observation and sagacity; whereupon the youth promised, immediately that his leg would permit of his accompanying him, to point out to Mr. Wedgwood the places where he had noticed the finest deposits of felspar to occur.

The conversation then changed to a subject that Mr. Josiah Wedgwood said "he had no doubt would be highly interesting to one of Humphry's turn of mind." The old gentleman told the boy how his brother Thomas had discovered a means of copying pictures upon glass, and even of fixing the images of the *camera obscura*, by the action of light; "so that," he said, "the sun itself could be made to turn artist, and to produce a representation of an object that no human hand could possibly rival."

Humphry was enraptured with the new wonder, and more eager than ever to learn all about it; so he begged Mr. Thomas Wedgwood to explain to him the whole process.

"I should tell you, then," said the potter's brother, "that it has been long known to chemists that a solution of *nitrate of silver* (called *lunar caustic* in the shops), when washed over a sheet of paper—although it does not undergo any change while kept in a dark place—will speedily change colour on being exposed to daylight, and that then it passes through different shades of grey and brown, and ultimately becomes nearly black. These alterations in colour," continued Mr. Thomas Wedgwood, "take place more rapidly according as the light is more intense. In the direct beams of the sun, two or three minutes are sufficient to cause it to darken; whereas in the shade, several hours are required to produce the full effect. The light, too, when transmitted through different-coloured glasses, acts upon the nitrate of silver with different degrees of intensity. It is found, for instance, that the sunbeams, when passed through red or yellow glass (so that only red or yellow light shall fall upon the paper), have very little action upon the lunar caustic; green glass, however, is more efficacious, while blue and violet produce the most decided and rapid changes.

"Now to make you clearly comprehend," went on the gentleman, "the reason of these changes, I should tell you that nitrate of silver consists of nitric acid (aquafortis) and silver,* and that if a vessel of pure and colourless nitric acid be exposed to the sun's rays, it will become decomposed, so that red fumes of nitrous acid will be evolved, and these mixing partly with the liquid itself, will shortly turn it to a reddish-brown tint. Well, the same change takes place when the nitric acid is combined with the silver, and so made to form nitrate of silver. The consequence is, that as the nitrous acid which is evolved is unable to combine directly with the silver, the decomposed aquafortis is dissipated in the form of vapour, while the silver itself remains behind in the paper; and in such an extreme state of minute division, that the particles, instead of being white, like ordinary silver, appear black to our eyes."

Humphry expressed himself delighted with the explanation, and said he could now see how it was possible to produce sun-pictures by such means. Still he begged Mr. Wedgwood to proceed.

That gentleman then told Humphry that his first attempt concerning the production of sun-pictures, was to fix the evanescent images formed by the camera obscura, but though he was able to impress

* For the sake of simplicity, the nitric acid is here made to consist (according to the new theory) of NO_6+H (instead of NO_5+HO), and so to combine directly with the metal as NO_6+Ag (instead of with the oxide as NO_5+OAg).

these upon paper in a bright sunlight, he found that he could not produce them in any moderate time in ordinary daylight; so that, from the length of time required before the impression was taken, the effects of light and shade had materially altered. "With paintings on glass, however," he added, "I have been more successful; in order to copy these I apply the solution of nitrate of silver to leather, for this I find to be more readily acted upon than paper—probably owing to the tanning in the material. When the surface of leather is thus prepared, I place it behind a painting upon glass, and expose it to the solar light, when the rays, being transmitted through the different parts of the picture, produce distinct gradations of black and white, according to the lights and shades in the original; for where the light passes freely through the glass, the colour of the nitrate of silver, of course, becomes the deepest. By this means, then, you will perceive that the lights and shades of my picture are entirely reversed: all the black parts in the original being left white in the copy, since the light, being unable to pass through these, cannot act upon the solution; while all the white parts of the original, on the other hand, become the blackest in the copy, owing to the rays passing freely through the glass there, and so producing the strongest effect. Accordingly, I am obliged to have the original pictures painted, in the first instance, with their lights and shades reversed, or else I cover another glass with a thin coating of isinglass, and apply the solution of nitrate of silver to this; so that, when I have transferred the original picture by this means to a second plate of glass, in which the lights and shades are the direct opposite to what they are in nature, I proceed to take a second copy of it—but this I do upon leather, as before explained—and so obtain a perfect reproduction of the original, with all the lights and shades in their proper places.

"But the same method of copying," proceeded Mr. Wedgwood, "may be applied to other purposes. It may be rendered subservient, for instance, for making delineations of all such objects as are partly opaque and partly transparent, such as leaves and the wings of insects. For this purpose it is only necessary to put the objects to be copied between a plate of glass and the prepared leather itself, when the sunlight, being more or less intercepted by their forms, will leave the figures accurately impressed upon the leather, so that they will appear as beautiful white pictures upon a black ground. There is, however," added Mr. Thomas Wedgwood, "one great defect connected with the production of sun-pictures by the means I have described, and this consists in the impossibility of fixing them so that they shall be no longer susceptible of being darkened when exposed to the light. I have already tried several methods of obviating this difficulty. I have covered the sun-pictures with a thin coating of varnish, but to no purpose, for they darken almost as rapidly with the varnish over them as others do without it. Again, I have submitted the pictures to frequent washings, in the hopes of dissolving out of the paper or leather all the undecomposed nitrate of silver; yet, even after this, a certain portion of the active matter still adheres to the white parts of the sun-picture, and so causes them to blacken all over on being exposed to the light. The consequence is, that the pictures produced by the action of the sun must, in order to be preserved, be examined always in the dark, and be kept continually in some place where no light can penetrate."

Humphry no sooner heard this than he suggested a number of expedients by which he fancied the difficulty might be overcome; and as the lad explained his reasons for the various methods he proposed, both Mr. Wedgwood and his brother were as astonished at the extent of the boy's knowledge, as they were delighted with the acuteness of his sagacity.

The evening was passed in examining a portfolio of the sun-pictures that Mr. Thomas Wedgwood had brought with him, and Humphry grew so charmed with the then entirely novel process of "*photography*," that he declared he would not rest until he had investigated the matter himself, and ascertained experimentally whether any means could be found of rendering the pictures permanent.

CHAPTER XIV.

THE WONDERS OF THE REFRACTION OF LIGHT.

Our young hero was still too weak to leave the house, for the wound in his leg was of so dangerous a description that Mr. Borlase had strictly enjoined him to take as little exercise as possible; consequently, while Humphry's evenings were passed in conversation with young Mr. Watt, and occasionally the Wedgwoods, his mornings were spent in his chamber alone, so that he was glad to resort to study as a means of enlivening his solitude.

Still the lad wanted some incentive to stir him to enter upon a fresh branch of science. This, however, he had now found in the wonderful photographic impressions Mr. Wedgwood had shown him, and he was eager to make himself acquainted with the laws of the mysterious principle by which they had been obtained.

The contemplation of the sun-pictures naturally led Humphry to think of the more transient pictures formed in the *camera obscura* by the light; and he passed from the fixing of the images to the consideration of the conditions by which the images themselves are produced.

"How comes it," he mentally inquired, "that a piece of glass, merely because it is rounded on one or both sides, is able to copy the forms and colours of external objects? And why do several of such glasses, in combination, bring the images of even the most distant things so close to us, that we are enabled to make out their minutest parts?"

Humphry knew that the effect could arise only from some alteration in the direction of the rays of light as they passed through the glass itself; and, accordingly, he determined to set to work and discover the precise change that a luminous ray undergoes on traversing different substances.

In the first place, however, it was necessary to determine what was the *natural* direction of a ray of light emitted by a luminous body.

For this purpose Humphry—who was still unable to undergo the exertion of arranging his own experiments—had to avail himself of the assistance of his sister Kitty; and so pleased was the girl with the office, that she readily gave up to her brother every moment she could spare from her household duties.

Kitty Davy was some two years younger than Humphry himself, so that they had been infant playmates together, sharing the same toys and taking parts in the same childish gambols. It was to Kitty, too, that the boy had first recounted the fairy stories he loved to invent; and when, in his after-youth, Humphry compounded his celebrated "thunder-powder," Kitty invariably aided him in the manufacture of the composition: so that each year had served to increase the love which, from the remembrance of the pleasures they had enjoyed together, had been begotten almost with the dawn of memory itself.

Kitty was now budding into womanhood. She had grown so tall within the last year, that her figure was spare, and not particularly comely; while the curls, which once fell, with childish beauty, in tortuous profusion about her neck, had now been displaced, and her hair twisted into the more womanly, but less gainly, protuberance at the back. This style of head-dress had long been a point of ambition with the young lady, and now that she had risen to the dignity of wearing her hair like her mother, Miss Kitty had grown to fancy that she was no longer a child.

Nor was she. The increasing strength of her affection for her brother showed that her woman's nature was developing, and she seemed to cling to Humphry and her mother with a new tenderness, as if she needed some one to heap her strengthened love upon. The doll upon which she had, until the last year or so, bestowed her caresses, had been given to one of her younger sisters; and now she appeared to take almost a mother's pride in tending little Johnny, her brother, instead.

Humphry during his illness had been constantly "nursed" by her, and now that she was allowed to officiate in the kitchen, the girl loved to surprise him each day with some new posset or jelly which she had prepared for his gratification. She had read to him, too, so long by his bedside from the scientific books which her brother loved to listen to, that, aided by his explanations of the more difficult parts of the subject, she herself had acquired a slight knowledge of the phenomena of the universe: so that, while assisting him in his experiments, she felt almost the same taste for the work as Humphry did, and was not a little delighted when the hour came for her to take her accustomed post in her brother's sick chamber.

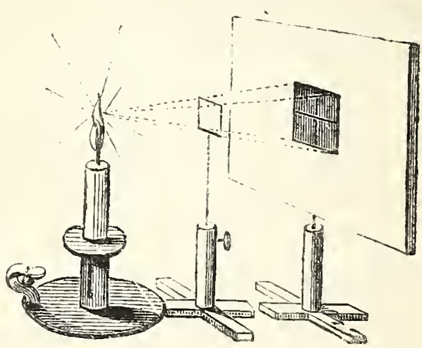
Humphry, as we said, was intent upon discovering the natural direction of a ray of light proceeding from a luminous body. With this view he got Kitty to close the shutters so as to completely darken the room, and then to pierce a fine hole through them. This being done, Humphry pointed out to the girl that the beam was in a perfectly straight line—for the course of it was rendered plain by the little particles of dust that floated in the atmosphere, flashing, as they danced in the ray, like so many tiny fire-flies. Then as Kitty wheeled her brother's chair so that the light fell directly upon his eye, the boy could see the sun itself shining through the hole; thus proving that the beam proceeded in a direct straight line from the orb of light to him.

The next step was to procure a flexible tube, and with this held *straight* before the eye, Humphry could still distinguish the sun through the hole in the shutter, though when the tube was *curved* the effect was totally different, for then no light at all could be perceived.

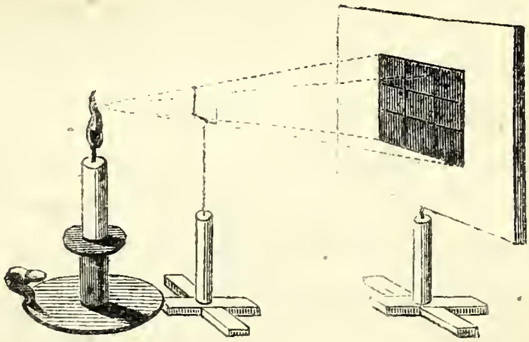
Kitty was not a little delighted with the demonstration that a ray of light proceeds in a straight line; and Humphry, to make her understand, as well as to prove to himself experimentally, that all luminous bodies *projected an infinity of such straight rays in every possible direction*, bade the willing girl fetch him the rushlight and shade from below.

While the shutters were still closed the candle was lighted, and then Humphry pointed out to his sister how the little luminous circles that were spattered over the wall all round the room, as the light passed through the holes in the shade, showed that the rays proceeded from it in every direction; and that they travelled in a straight course was easily proved, by covering with the finger any one of the holes in the shade, when the luminous circle on the wall, which was in a direct line with the hole, and the flame became immediately obscured.

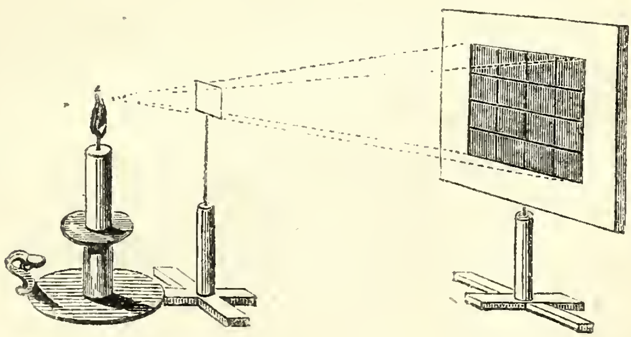
It was plain, then, that a ray of light travelled naturally in a straight line. Still, as a further proof of this phenomenon, Humphry threw the shadow of an opaque body, of a certain size, upon a white screen, and there measured its dimensions. Having cut a piece of millboard, exactly a foot square, he placed it 1 foot distant from the flame of a candle, and then arranging the screen at double the distance, or two feet from the light, he found upon measuring the shadow of the millboard that it was exactly (2×2) 4 times larger



than the millboard. When the screen was three feet distant from the candle, or 3 times as far from the light as the millboard, the shadow was ascertained to be (3×3) 9 times larger than the surface from which it was projected; while at the



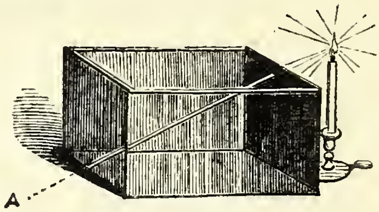
distance of 4 feet, the dark space upon the screen was discovered to be (4×4) 16 times greater than the millboard itself.



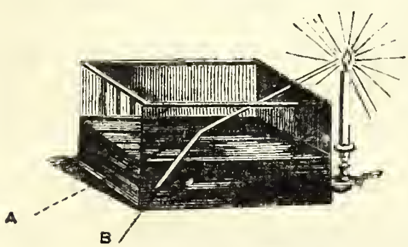
This effect could arise solely from the rays of the candle proceeding in a straight direction, as will be rendered evident by the preceding diagrams; where it will be seen that the opaque body, interposed between the light and the screen, prevents the rays which fall upon it reaching the screen itself, so that a dark space appears upon the latter, as many times larger than the opaque body, as the distance of the screen from the candle is greater than the body projecting the shadow; for it is manifest, that if a series of right lines be drawn from the luminous point to the edges of the opaque body, and thence to the screen itself, they will exactly circumscribe a space whose dimensions will be proportional to the distance of the one to the other.

"Well," said Humphry to his sister, "we now see that luminous bodies *emit* rays of light *in all directions*, and that each ray from them proceeds in a *straight* line, while those substances which are called opaque prevent, when placed before the light, the rays from reaching other substances behind them—the rays, in such cases, being *stopped* or intercepted. Some bodies, however," added the boy, "are capable of *transmitting* the rays of light: that is to say, they allow the beams to pass through them, and these are, therefore, termed transparent; since, unlike opaque bodies, they project no shadows when placed between the light and other bodies. Let us now see what occurs when a ray of light passes through a transparent body."

Accordingly, Humphry procured a small open vessel, in one of the sides of which there was a hole near the top, large enough to admit the light from a candle. The lad then proceeded to ascertain the exact place where the ray of light from the flame fell at the bottom of the vessel; and found that, when the vessel was empty and the candle placed at a short distance from the hole, there was a small circle of light formed at the bottom, which was, of course, in a direct line with the hole and the flame, as here shown.



Having then set a mark at A, where the circle of light appeared, he directed Kitty to pour water into the vessel until it was half full; and when she had done so, he noticed that the ray of light from the candle no longer fell upon the same spot as it did when the vessel was empty, but at a little distance nearer the candle, so that it was plain that the ray, instead of proceeding in a straight line as before, had, in passing through the water, *been bent down out of its usual course*, in the manner indicated at B.

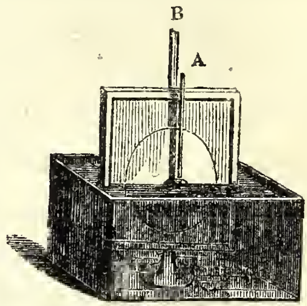


"You see, then," remarked Humphry, "that a ray of light, when it falls in a *slanting* direction upon a transparent body, *no longer travels on in a straight line, but is refracted*," as it is called, "*or bent* *out of its previous course, at a certain angle.* Consequently, if the spot B was a fish lying at the bottom of a river, it would be seen by a person on the shore in the direction of the point A; and thus it would appear out of its true place, and, in order to strike it with a spear, we should have to direct the weapon at a spot *nearer* to us than where the fish *seemed* to be lying."

Then her brother told her that it was for the same reason that a straight stick appeared to be crooked when half immersed in a pool of water, and a crooked stick a straight one under the same circumstances; "for," said he, "if instead of the straight ray of light we imagine a straight stick to be passed through the hole, so that the point of it may be at the spot A, it is plain that in the water the end of the stick will appear at B, since the part of it which is immersed will seem to be bent in that direction; whereas if the stick itself be bent, so that the end of it is at B, it will, for the same reason, appear when in the water at A, and, consequently, seem to be perfectly straight.

The next step was to try and measure the *degree* of refraction, or, in other words, to find out how much a ray of light was bent out of its usual course on passing through different transparent substances.

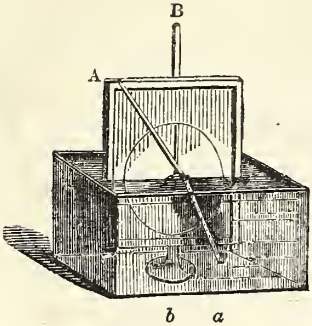
Accordingly, Humphry procured his old school-slate, and having managed, with Kitty's assistance, to mount this on a heavy pedestal, he described upon the slate a circle with two diameters, each perpendicular to the other; then having bored a hole in the centre, he fitted into it a large cork; this had a straight tube afterwards let into it, so that the tube, by means of the cork in the middle, could be moved freely round the circle, turning, as it did, upon the centre of it. The whole apparatus was then inserted in a vessel of water, so that the fluid reached exactly to the level of the horizontal diameter—thus, without touching the end of the tube.



The youth then found, that when the tube A was directly perpendicular to the surface of the water, a ray of light, on passing down it, suffered no change at all in its direction; and that on placing a sixpence in the water, exactly in a line with the perpendicular diameter, B, it could be seen distinctly through the tube, so that the rays from the coin, on quitting the water, proceeded in the same straight course as they had pursued while passing through the fluid.

Hence it was evident that a ray of light, on *entering or quitting a refracting surface in a* PERPENDICULAR LINE, *is not refracted or bent out of its course.*

It was different, however, when the tube was



slanted, instead of being placed *straight* above the surface of the water, for when a ray of light passed down it in that direction, the ray was found to be refracted, or bent out of a straight course, as shown in the above diagram.

Now the precise direction of the refracted ray having been marked upon the slate, the apparatus was removed from the water, and the distance of the tube A from B, the vertical diameter, measured, as well as the distance of the refracted ray, *a*, from the same perpendicular line, *b*, and it was then found that the refracted ray, *a*, was as near as possible 3 inches from the diameter, *b*, while the ray A, which passed down the tube, was as much as 4 inches distant from B, the same line.

The tube A was then set at about $1\frac{1}{3}$ inches from the diameter B, and the apparatus replaced in the water, when it was discovered that a ray of light, *a*, on passing down it, fell exactly at 1 inch from *b*, the perpendicular line.

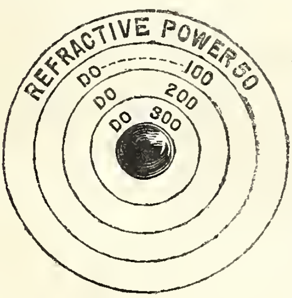
Several other positions of the tube were afterwards tried, and invariably with the same result: let the tube be slanted as it might, the distance A . . . B of the ray which passed down it, when compared with the distance *a* . . . *b* of the refracted ray from the perpendicular line, was *always ascertained to be in the same proportion*—viz. very nearly as $1\frac{1}{3}$ to 1; or, more correctly speaking, when A . . . B, the sine of the angle at which the ray entered the water, was $1\frac{1}{3}$, then *a* . . . *b*, the sine of the angle formed by the refracted ray, was exactly 1.

On referring to his books, Humphry found that the number $1\frac{336}{1000}$ constituted what was termed the *index of refraction* for water.

On performing the same experiment with oil of turpentine the lad discovered, that when the ray which passed down the tube was almost as much as $1\frac{1}{2}$ inch distant from the perpendicular, the refracted ray was 1 inch distant from the same line; whereas with sulphuret of carbon (though with this the experiment was performed on a smaller scale), when the ray passing down the tube was $1\frac{2}{3}$ inch removed from the perpendicular—the refracted ray was still only 1 inch away from the same line.

Humphry then consulted a table of the refractive power of different bodies, and learned that hydrogen gas is the least refractive of all known substances (that is to say, a ray of light passing through this gas is bent down by it out of its previous course, less than by any other known body), and that the diamond has very nearly the greatest refractive power of all, while the refraction of the air in its ordinary state is only 294 millionths greater than that of a *vacuum.*

This, however, is the refractive power of the atmosphere at its average density near the earth's surface. But we learn from the barometer that the density of the air diminishes as we mount above the earth, and it has been found by experiment that the refractive power of the atmosphere decreases in proportion as it becomes more and more rarified; so that the atmospheric refraction is greatest at the earth's surface, and gradually diminishes upwards, till the air becomes so rare as to be able to produce scarcely any effect at all upon the rays of light.

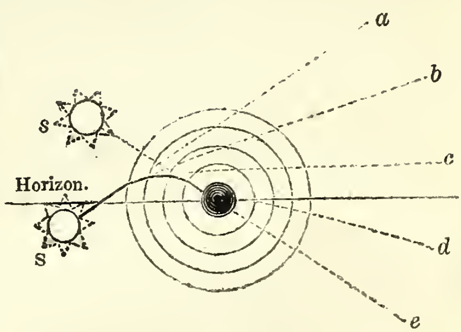


"In order to understand this," said Humphry to his sister, "we must consider the earth to be encased in a series of shells, as it were, of atmosphere, each of a less density than the one below it, and, consequently, of a less refractive power—thus.

"Let us suppose," the lad continued, "the round ball in the centre here to represent the earth, and the ring of atmosphere immediately next to it to have a refractive power nearly 300 millionths greater than a vacuum; and the refractive power of the ring, or shell of atmosphere immediately above this, to be equal to only 200 millionths compared with the same standard, while the power of the third ring decreases to 100 millionths, and that of the outer one to 50 millionths, whereas beyond this no refraction whatever exists, so that the rays moving through free space will continue in the same line as that in which they are emitted from the sun. What, then, will be the effect of such a series of atmospheric shells upon a ray of light passing through them?"

To illustrate this Humphry drew the lines here shown through the following diagram.

"The orb S, outside the earth," continued Humphry, "represents the sun below the horizon, emitting, let us suppose, his rays in all directions. These, passing through free space, proceed onwards in a perfectly straight line; and one of them is here made to fall upon the outer ring of the earth's atmosphere, where it is slightly refracted, or bent down out of its former course, so that, instead of continuing in the direction of the dotted line *a*, it proceeds through the upper portion of our atmosphere in the direction of the unbroken line, until it reaches a part of the atmosphere of greater density —as in the second ring; when, instead of going on



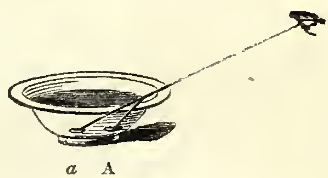
in the direction of the second dotted line *b*, it is again refracted, or bent down, in a greater degree than before. Then travelling onwards, it reaches the third ring, where the atmosphere, being of a still greater density, and, consequently, having a greater refractive power, it is once more bent out of its course *c*, and that to a still greater extent than before. In this manner it ultimately arrives at a stratum of atmosphere which immediately envelopes the surface of the earth, and which, having the greatest density of all, has the greatest refractive power; so that the ray, instead of continuing in the direction *d*, is here bent down more than ever, and finally reaches the eye in the direction *e*, which is in a direct line with the orb *s*. The consequence is, that as *every object is seen in the direction that the ray has at the instant of arriving at the eye*, the sun itself appears to be *above* the horizon when it is positively *below* it, as at S; so that, by the refraction of the atmosphere, the sun is seen by us before he rises in the morning, and for a short time after he sets in the evening."

Kitty was so astonished at the above conclusion, that, though she understood the explanation, she told her brother that she could hardly help doubting the fact; saying, "it was almost the same as asserting that we could see a thing that was out of sight."

Humphry undertook to prove to his sister, by experiment, that such a result was quite possible by refraction.

Accordingly, he bade Kitty place the wash-hand basin upon the table, and then having deposited a shilling at the bottom of it, he told the girl herself to recede from the table until the edge of the basin obscured the shilling from her sight; and when Kitty assured him that she could no longer see the coin, he poured some water into the vessel, and immediately the girl exclaimed—"Dear, dear, how odd! I can see the shilling quite plainly now."

"You perceive, then, Miss Kitty," cried the boy, triumphantly, "it is quite possible by refraction to see things that are out of sight, for the ray from the shilling, A, on passing out of the water into the air, is bent out of its course, and you behold it in the direction of the line in which it enters your eye—thus, at *a*.

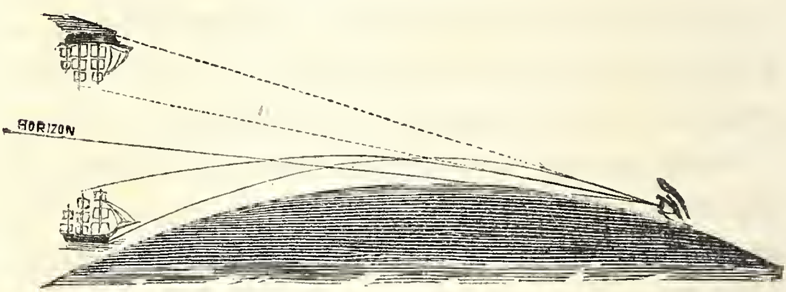


"But far more wonderful things than this have been brought to pass by the same means, Kitty," said her brother, delighted to impart the knowledge he had obtained from his books on this subject, "and these are what are called *mirages*, or optical illusions, produced by extraordinary refractions in the atmosphere. For instance, the cliffs on the French coast are 50 miles distant from Hastings, on the coast of Sussex, and they are actually hidden from the eye by the convexity of the earth; that is to say, a straight line drawn from Hastings to Calais or Boulogne would pass through the sea. A year or two ago, however, Mr. Latham, a Fellow of the Royal Society, who was residing at Hastings, was surprised to see a crowd of people running to the sea-side. Upon inquiry into the cause of this, he was informed that the coast of France could be seen by the naked eye. He immediately went down to the shore to witness so singular a sight, and there discovered distinctly the French cliffs extending for some leagues along the horizon, and so vividly that they appeared to be only a few miles off. The sailors and fishermen, with whom Mr. Latham walked along the water's edge, could hardly, at first, be persuaded of the reality of the appearance; but as the cliffs gradually became more elevated, they were so convinced that they pointed out to Mr. Latham the different places they had been accustomed to visit: such as the bay and the windmill at Boulogne, St. Vallery, and other places on the coast of Picardy, even as far as Dieppe, all the French shores appearing to the English sailors as if they were sailing at a short distance from them towards the harbours. With the aid of a telescope the French fishing-boats were plainly seen at anchor, and the different colours of the land upon the heights, together with the buildings, were perfectly discernible. The day when this occurred is said to have been extremely hot, without a breath of wind stirring, and the phenomenon continued visible in the highest splendour until past 8 o'clock in the evening, having been seen for three hours continuously."

Some few years after the date of the above, a no-less-marvellous optical illusion was seen by Professor Vince of Cambridge, in company with another gentleman, at Ramsgate. Between this town and Dover there is a hill, on the farther side of which stands Dover Castle, the summits of whose four turrets can, in ordinary states of the atmosphere, be just seen projecting above the brow, while the body of the castle itself is usually hidden from view by the rising earth between it and Ramsgate. On the evening of the 6th of August, 1806, however, when the air was very still, and a little hazy, not only were the tops of the four towers of the castle visible above the brow of the hill in the distance, but the *whole* of the castle itself appeared transferred to the side of the hill next Ramsgate, as if it had been really built there, instead of on the other side of the eminence. This phenomenon was so singular and unexpected that Dr. Vince, at first sight, thought it an illusion. On continuing his observations, however, he became satisfied that what he saw was a real image of the castle. To assure himself that it was no deception, he gave the telescope to a gentleman who was with him at the time, and who also saw the same clear image of the entire castle, situate on the near side of the hill, as the Doctor himself had witnessed. The view of the castle was very strong, and well defined; and though the rays from the farther side of the hill must, undoubtedly, have reached the eye at the same time, still the strength of the image of the castle itself so far obscured the background that it made no sensible impression on the spectators. Dr. Vince continued to observe the image for about 20 minutes, during which time the appearance remained precisely the same, but rain then came on, and he was prevented making any further observations.

Humphry now began to study how, by means of extraordinary refraction, inverted images of objects might be seen in the atmosphere.

With this view he drew the subjoined diagram,



"There, Kitty," said the lad, as he laid down his pencil and compasses, "the drawing represents a ship below the horizon, and concealed from the eye of an observer by the convexity of the earth. Well, if we suppose the refractive power of the air at a little above the earth's surface to be less than it is at the surface itself, then the rays which proceed upward from the ship, and which never could, in the ordinary state of the atmosphere, reach the eye in the position here shown, will be refracted into curved lines, so that they will cross one another; while the ray which came from the masthead, instead of being uppermost, will change places with that coming from the hull, and becoming the undermost of the two, will enter the eye in that position: consequently, as every object is seen, as I said before, *in the direction of the rays at the moment of their arriving at the eye, without reference to their previous course*, an inverted image of the ship will be perceived in the air, in the direction of the dotted lines, and thus appear elevated above the horizon."

Kitty said she could hardly follow the explanation, and wished to know whether her brother could not devise some experiment in proof of it.

After a few moments' consideration, Humphry requested his sister to fetch him a square phial, and to make him a little clear syrup with some lump-sugar and water. When this was prepared, the boy poured a small quantity of the syrup into the phial, and upon this again he poured very carefully an equal quantity of pure water, so that it might float upon the syrup. Now the syrup, being a fluid of greater density than the water, had a proportionately greater refractive power, and as the two combined with each other they formed strata, having different refractive powers, the same as those which had been supposed to exist in the atmosphere at certain times, at a little distance above the surface of the earth. Then having printed the word SYRUP upon a card, Humphry held this behind the bottle, and the letters were seen *erect* through the stratum of syrup at the bottom, but *upside down* at the part where the syrup was mixing with the water, and *erect* again through the layer of water itself at the top.

After this the lad poured the same quantity of spirits of wine carefully over the water itself, so that the spirit being lighter than this might float above this again; and then having printed the word SPIRIT on the upper part of the same card, the letters of this were seen *erect* through the layer of water, but *topsy-turvy* at the part where the spirit and water were mingling, and in their *proper form* through the uppermost stratum of spirit itself.

Humphry afterwards produced the same effect by holding a heated iron above a tumbler of water, so that the upper surface of it became warmed while the lower remained cold, and the portion in the middle became tepid. The heat, therefore, expanded, and so rendered rarer the upper portions of the liquid; and as it forced its way downwards, produced strata of different densities, and, consequently, of different refractive powers. The result was, that on looking through the glass vessel three images were seen as before; the upper and the lower ones—which arose from the rays passing through the colder and the warmer strata—being erect, and the middle one, or that which proceeded from the rays passing through the portion in the middle, being inverted—as previously observed. The same effect may be produced by looking along the side of a red-hot poker, at an object 10 or 12 feet off, when an inverted image will be seen at the distance of about $\frac{3}{8}$ths of an inch from the line of the poker, and an erect image within and without this.

The youth, having now demonstrated to his sister how it was possible to produce three distinct images, and one of these inverted, from the same object, when seen through strata of different densities, proceeded to recount to Kitty stories of similar phenomena observed at sea. He told her how Dr. Vince had seen at Ramsgate a ship whose topmasts only were visible above the horizon, while over this, in the air, two images of the complete ship were observed, the uppermost being *erect*, and the under one *inverted*, with the pennant from the masthead of the inverted image nearly touching that from the real ship, seen peeping above the horizon. This was distinctly visible through the telescope; the sea appearing between the two ships in the air, as here represented:

"As the ship rose to the horizon," said Humphry, "the upper image gradually disappeared, and while this was going on the lower and inverted image as gradually descended; but the mastheads of the real and the spectral inverted ship never exactly touched. On the real ship becoming entirely visible, the aërial images were found to have been perfect representations of it, even though the whole of the vessel at the time must have been concealed below the horizon."

There is, however, it may here be added, a still more marvellous story in connexion with this part of the subject, though it occurred at a more recent date than that recounted by Humphry. During a voyage to the coast of Greenland in the year 1822, Captain Scoresby, having seen an image of an inverted ship in the air, directed his telescope to it, and was able to discover that it was *his father's vessel, which was at the time below the horizon, and cruising in a neighbouring inlet.* "The image," says the captain, "was so well defined that I could distinguish by a telescope every sail, the general 'rig of the ship,' and its particular character, insomuch that I confidently pronounced it to be my father's ship the 'FAME,' which it afterwards proved to be; though, on comparing notes with my father, I found that our relative position at the time gave our distance from one another 30 miles, which is about 17 miles beyond the horizon, and some leagues beyond the limit of direct vision. I was so much struck by the peculiarity of the circumstance," adds the captain, "that I mentioned it to the officer of the watch, stating my full conviction that the 'Fame' was then cruising in the neighbouring inlet."

The same officer, while navigating the Greenland sea in 1820, saw the images of several ships in the air. Some of these were double, and inverted, while along with them there appeared aërial images of the ice, in two strata; the highest of which had an altitude of a quarter of a degree.

The representation of ships in the air by unequal refraction has, no doubt, given rise in early time to the superstitions of phantom-ships, which are always said to sail in the eye of the wind, and to plough their way through the sea when there is not a breath of wind to ruffle its surface. The story of the "Flying Dutchman" had, probably, a similar origin; and the legend of the wizard beacon-keeper of the Isle of France, who saw in the air the vessels bound to the island long before they were visible in the horizon, doubtlessly arose from the man's observation of some such phenomena.

CHAPTER XV.

THE WONDERS OF THE REFRACTION OF LIGHT (*continued*).

YOUNG Humphry now sought to discover the circumstances upon which the formation of images, or pictorial representations of objects, depends.

"In the first place," said he to his sister, "you must bear in mind that all objects throw off from them, in all directions, rays of light, which are of the *same colour* as the objects themselves. The soldier's coat appears red to us, because it sends *red rays to the eye;* the fields are green, because they emit rays of *green light;* and the summer clouds are white, because the light they reflect to us is of *that colour.* Indeed every flower, whatever may be its tint, is seen by us coloured as it is merely because the rays of light proceeding from it are of the *same hue as the flower itself appears in our eyes.*"

Kitty told Humphry that she could hardly comprehend this; saying, "that the pattern of the paper on the wall was green and yellow, and yet, let her look at it in whatever way she might, *she* could seen no green and yellow rays coming from it."

Her brother, however, assured her that, if *no rays* from the paper entered her pupil, she would not be able to see it at all; that is to say, the wall would appear absolutely *black* in her eyes; whereas, if the rays it reflected were *colourless*, it would seem perfectly *white* to her.

"In ancient times," continued Humphry, "it was believed that the eye itself had some peculiar power of emitting light, and thus of distinguishing objects by its own agency; but now we know that no such power resides in the organ of sight, the eye being almost *passive* during vision, and seeing only those objects *which emit or reflect rays of light to it:* for it is merely by such rays of light entering the pupil, and forming a picture of the object at the back of the eye, that we are enabled to distinguish the forms, as well as the colours, of the things around us. So you must bear in mind, Kitty," he added, "that the figures and tints which you see *come to your eye, instead of your eye sending out anything to them;* for, were it otherwise, you would be able to see without any light at all."

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Humphry then applied himself to prove, experimentally, that all objects send off rays of light of the same colour as themselves.

Accordingly, he took an empty cigar-box, and having drilled a fine pin-hole at one end of it, he bored another small hole in the lid—the latter being for the purpose of looking through. Then, inside the box, at the end opposite the pin-hole, he pasted a piece of white paper, and placed a rose-tree at some short distance in front of the box itself, so that the rays of light from the plant might pass through the pin-hole, and be projected upon the white paper at the farther end of the dark box.

The arrangement being complete, he bade Kitty apply her eye to the hole in the lid, and tell him what she saw.

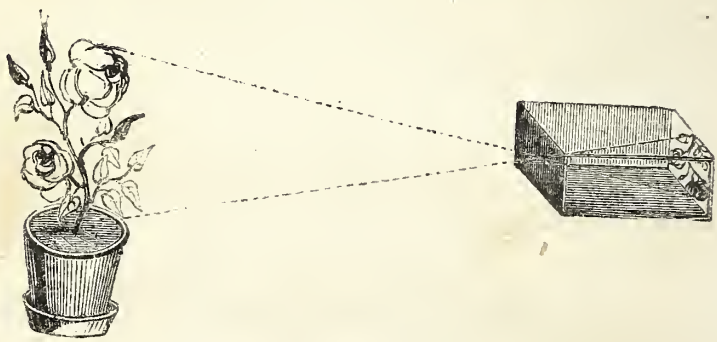
"Dear, dear!" cried the astonished girl, "I declare if there isn't a little tiny picture of the rose-tree painted on the paper inside the box. It isn't very plain though, Humphry; but I can just see patches of red for the roses, and patches of green for the leaves."

"Yes," said her brother, "and how could the colours come there, unless the plant itself was giving off different tinted rays from its leaves and flowers?"

"But, Humphry," the girl exclaimed, as she continued gazing through the hole, "I *do* believe it's upside down; for the patches of red that I see are below the green, and in the rose-tree itself the flowers are up above, and the leaves underneath. How very strange!"

The lad having had a peep himself at the image, proceeded to explain to Kitty the reason of the picture appearing inverted.

With this view he drew the annexed diagram:



"The rose-bush," said he, "is sending off rays of light in all directions. Well, let us suppose two of these rays to pass through the pin-hole in front of the dark box, one coming from the top, and another from the bottom of the plant. Now the consequence would be, that the two rays, on passing through the pin-hole, would cross each other; so that the one which was uppermost would be transferred to the lower part, and that which was originally the bottom ray take the place of the top one. Hence it is plain that the image, or picture, of the object must appear upside down."

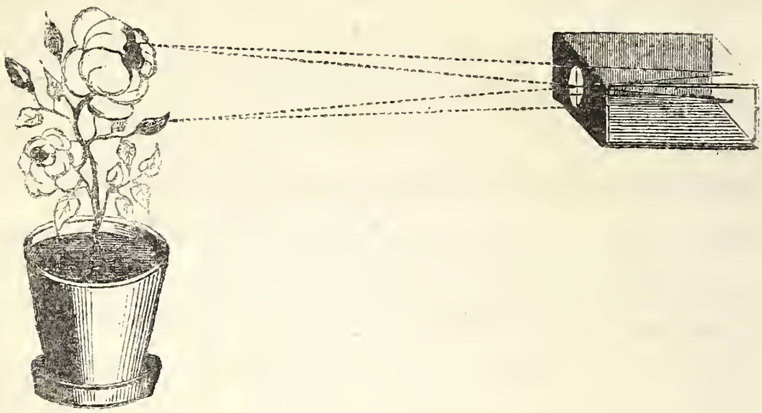
Kitty was perfectly satisfied with the explanation, but, wishing to see the picture of the rose more plainly upon the paper, she asked Humphry whether he could not admit more light into the box.

The brother smiled at the simplicity of the request; but, to let the girl see the result of enlarging the light-hole, he set to work to make a greater aperture in front of the box. This done, he told Kitty once more to peep through the hole in the lid.

"Why, what's the matter with it, Humphry?" cried the sister; "I don't see anything at all now."

Humphry smiled at his sister's wonder, and proceeded to recount to her the reason why the picture had become obliterated. He told her that when the hole was a very small one, no two rays from different parts of the object fell upon the same place; but that, now the whole was enlarged, the rays that were being sent off in all directions from every part of the rose-tree became confused with one another, so that those from the green leaves fell upon the same part of the paper as those from the red flowers, and the consequence was that the one colour obliterated the other.

For the easier comprehension of this part of the subject, Humphry drew the subjoined representation of the rays proceeding from one of the flowers



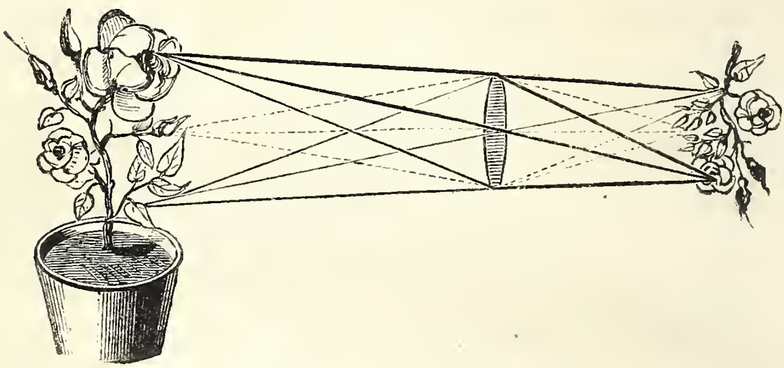
and one of the leaves; where it will be seen that, owing to the enlargement of the aperture at the front of the box, the red ray from the flower, and the green ray from the leaf, fall upon the same part of the paper at the back; for as the leaf and the blossom each send off rays in all directions, it is evident that—supposing only two of these, for simplification' sake, to pass through the aperture—one of the green leaf-rays would fall upon the same spot with one of the red blossom-rays, and one of the blossom-rays, on the other hand, become blended with one of the leaf-rays.

Kitty was not a little disappointed at the result which had followed the enlargement of the light-hole; but Humphry, to console her, said that it was possible, by means of a lens, to increase the light, and yet to *prevent* the rays from different points of the object falling upon the same part of the paper at the end of the box.

For this purpose the lad placed a double convex lens, which he had previously made out of two watch-glasses cemented together, into the aperture at the front of the cigar-box, and then told his sister to look once more through the hole in the lid.

Kitty no sooner applied her eye to the sight-hole than she cried aloud, "O how beautiful! I declare it is much brighter than the first, and I can now see every leaf and blossom perfectly made out. It's the picture of a little fairy rose—that it is. But tell me, Humphry," said the girl, "how could a little bit of rounded glass like that which you put into the box produce so wonderful a change?"

"Well," returned the brother, "you recollect I told you that every object which we see is sending off rays of light from every part of it in all directions. In the first case, when there was a mere pin-hole in front of the box, the aperture was so small that only *one* ray from each point of the rose-tree passed through it, and, therefore, the image was so dim you could scarcely make it out. With the convex lens, however, as many more rays enter the box from every part of the plant, as the lens itself is bigger than the small hole which we had in the box at first; and the reason, again, why these rays are prevented from becoming confused one with the other, and so obliterating the picture —as was the case when we enlarged the light-hole in front of the box, without inserting any lens in it —is because they are all duly refracted by the lens, so that they severally fall in their proper places. But you will understand this better by a drawing." And, so saying, Humphry prepared the illustration below given:



"Here you see there are three rays," continued the lad, "drawn from the top, bottom, and centre of the object; three only are given for the sake of simplicity, though every point of the plant is sending light from it in the same manner as here indicated. Well, Kitty, the rays from the flower at the top of the tree fall upon every part of the glass, and, by the laws of refraction, are made to come together at a point on the other side of it.

Again, the rays from the leaves at the bottom of the tree fall upon every part of the lens, and are so refracted that they all meet at another point on the other side of the glass; while those from the rosebud in the centre are likewise blended into a focus at the same distance behind the lens. But you will perceive, that the rays which come from the upper part of the object fall at the lower part of the image; and those, on the other hand, which proceed from the top, fall at the bottom. This is because the rays from these parts cross one another in the centre of the lens, while those which are sent off from the rosebud in the middle suffer no change of position, because *they* proceed—as you observe by the dotted lines in the drawing—directly through the glass, rather than traversing it obliquely as the others do."

"Oh, thank you, Humphry," said Kitty; "I can make it out well now. The image from the lens is so much brighter because it not only allows more light to pass through the aperture, but prevents the rays from the different parts of the object mingling one with the other. But, Humphry," ejaculated the girl, as a new thought struck her, "the image, as you call it, is much smaller than the rose-tree itself: why is that?"

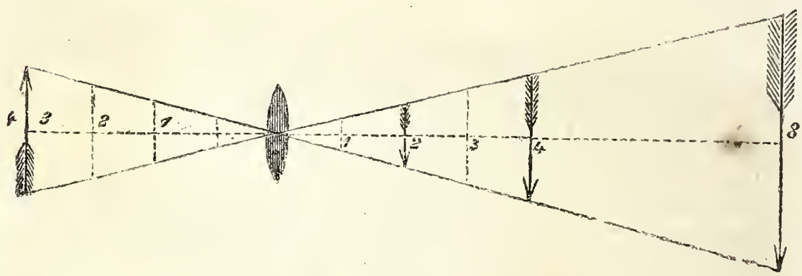
"To make you understand this, Kitty," answered the boy, "I will place the tree farther from the lens, and you shall tell me the effect."

Humphry had no sooner removed the plant to a greater distance, than the girl cried, "Oh, it's much smaller than ever now!"

"And now that I bring it nearer the box, what do you see?" inquired the youth.

"Why it seems to grow and grow, Humphry," replied Kitty, as she continued peeping through the hole in the lid, "so that I fancy it would get as big as the tree itself. The picture, though, is not nearly so bright."

"No," returned her brother; "that is because it gets out of focus. Now look you here, Kitty; I will do another drawing, to enable you to comprehend how the size of the image depends upon the distance of the object from the lens.



"You must bear in mind," proceeded Humphry, on the completion of the diagram, "that *the rays which pass through the centre of a lens never change their direction.* Well, I have drawn here, you see, one ray from the tip of the arrow, and one from the bottom; and as these rays necessarily form the extremes of the image, and so regulate its size, you will readily comprehend that, when the object is, as here represented, 4 yards, or feet—or, indeed, 4 measures of any kind—in front of the lens, and the image falls, also, at 4 such measures behind it, as at the arrow 4, the image itself must be exactly of the same size as the object. If, however, the image fell at half the distance behind the lens which the object was from the front of it, then the picture would be only half the size of the body producing it—as here, at the arrow 2; whereas if the image was at twice the distance of the object from the lens, as at the arrow 8, then it would be exactly twice the size of it. Consequently, the dimensions of the image produced by a lens bear always the same proportion to the object *as the distance of the object from the lens does to that of the image:* that is to say, if the object be 3 times as far from the lens as the image is, then the image will be 3 times smaller than the object itself, and *vice versâ*, if the object be 3 times nearer the lens than the image, then the image will be 3 times larger than the object."

Kitty having informed her brother that she thoroughly understood the matter now, Humphry went on to tell her that, in order to produce an image, it was necessary that the picture should be received upon some opaque or intransparent substance, otherwise the rays of light would pass *through* the substance itself without being reflected from it or sent back to the eye.

"The opaque body," continued the youth, "upon which the image is thrown, should be of a white colour, for this reflects the greatest amount of light."

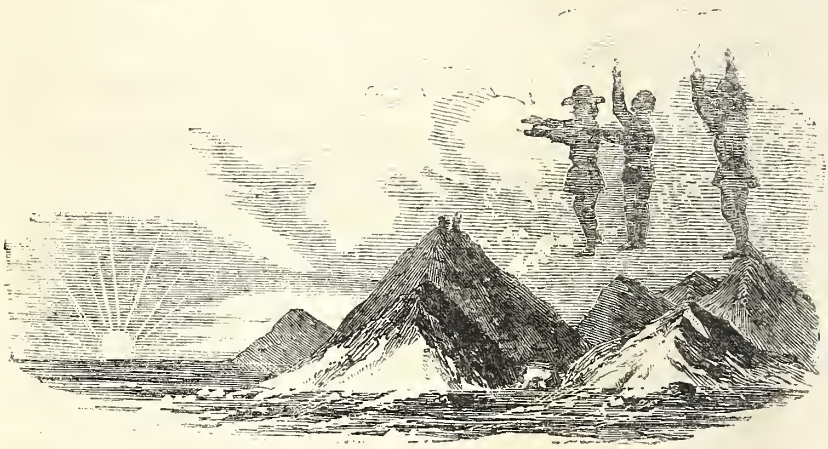
To elucidate this part of the subject, Humphry removed the wooden end of the cigar-box that he had previously employed, and substituted a piece of ground glass in its stead; when Kitty, on placing her eye behind the box, saw the picture of the rose-tree once more portrayed upon it.

"Now," added her brother, "if I smear the ground glass over with any grease, or even water, so as to increase its transparency, you will see that the image immediately disappears."

This done, Humphry explained to Kitty that the image might be received upon smoke, or, indeed, any vapour that consisted of a number of opaque white particles, and then he recounted to her the story of the "spectre of the Brocken."

"The Brocken," said he, "is the name given to the loftiest of the Hartz mountains, which is a picturesque chain of hills situate in the kingdom of Hanover. The highest of these is elevated 3300 feet above the sea, and commands the view of a plain upwards of 200 miles in extent. This spot has been the seat of the marvellous from the earliest periods. One of the accounts given of the 'Spectre of the

Brocken' is that of M. Haue. After having been on the summit of the mountain no less than thirty times, he had, at last, the good fortune of witnessing the object of his curiosity. The sun rose at about 4 o'clock in the morning through a serene atmosphere. In the south-west, towards Achtermannshohe, a brisk wind carried before it the transparent vapours which had not yet been condensed into thick, heavy clouds. About a quarter past 4 M. Haue looked round to see whether the atmosphere would afford him a free prospect towards the south-west, when he observed, at a very great distance towards Achtermannshohe, a human figure, of a monstrous size. At this moment a violent gust of wind ensued, and M. Haue suddenly raised his hand to his head, to prevent his hat being carried away, when, to his great astonishment, he beheld the colossal figure in the distance do the same. He immediately made another movement by bending his body, and this action, too, was instantly repeated by the spectral figure. There was now no doubt that what was termed the 'Spectre of the Brocken' was an enormous image of the spectator himself seen in the distance. M. Haue was desirous of making other experiments, but the figure disappeared. He remained, however, in the same position, expecting its return; and in a few minutes it again made its appearance on the Achtermannshohe, when it once more mimicked his gestures as before. M. Haue then called another person to him, and having both taken the same position which he himself had previously occupied, they looked towards the Achtermannshohe, but saw nothing. In a very short space of time, however, two colossal figures were formed above the eminence, and, after bending their bodies, and imitating the gestures of the spectators, they disappeared. M. Haue and his companion, nevertheless, retained their position, and kept their eyes still fixed upon the same spot, when the two gigantic spectres were again beheld by them, but this time they were joined by a third,



and, strange to say, every movement they made was imitated by *all the three figures*. The effect, however, varied in its intensity, being sometimes weak and faint, and sometimes strong and well-defined.

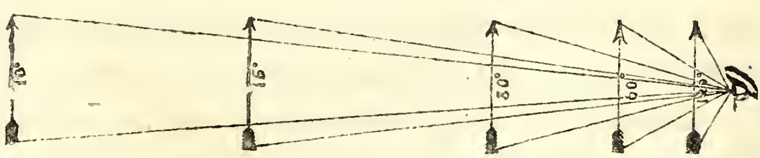
"These figures were merely shadows of the observers, projected on dense vapour, or thin fleecy clouds, which have the power of reflecting much light. They are seen most frequently at sunrise, because at that time the vapours and clouds necessary for their production are usually generated; and they can be perceived *only* when the sun is throwing his beams horizontally, because the shadow of the observer would be otherwise projected up in the air, or down upon the ground. It is very probable that the third figure observed by M. Haue was formed by a duplication of one of the others, produced by unequal refraction; though M. Haue himself does not state which of the two figures was doubled."

It may here be added, that another story of the same kind is told by Sir David Brewster. "A young lady had ascended to the top of the Mynydd, a steep hill, about 500 feet above the valley of New Rednor, in South Wales. The sun was bright and hot (it being about 2 o'clock in the day). Having picked some flowers on the top of the hill, the girl descended a little way, to a spot from which she could see the road and the carriage with her companions whom she had left in it below. After waving the scarf which she held in her hand to her friends, she suddenly perceived, upon turning round, a figure standing a few yards from her upon a wet spot, *from which a little thin mist was rising.* The figure stood exactly facing her, and wavered a little; but she did not discover it to be her own image, till she observed that, like herself, it held a scarf and a bunch of flowers in one hand. The dress and flowers were precisely similar to her own, and the colours so vivid that she could even trace her own features in the image. The effect was the same as if she had been before a looking-glass — when she moved her hand, the figure did the same. The two friends in the carriage saw the image of the young lady, and asked her, when she joined them, what companion she had had on the hill. There can be no doubt," adds Sir David Brewster, "that the figure was a reflexion of the young lady, produced by the thin mist rising from the damp ground; for it may be proved, by experiment, that when the particles of vapour are sufficiently small, they reflect light as distinctly as a surface of glass."

From the production of images, Humphry passed to the consideration of the circumstances by which lenses appear to *increase the size of objects*, and so to make them seem as if *brought nearer to us.*

"When a shilling," said Humphry, "is at the distance of 6 or 8 inches from the eye, we can read the inscription round it with perfect distinctness. At the distance of 3 yards, however, we can no longer make out the inscription, but see only the king's head upon it. Again, at the distance of only 20 or 30 yards, we lose sight of the head, and can then just distinguish that it is a round body; whilst, when placed at about 100 yards from us, the coin is scarcely visible. The reason of this is, that the shilling decreases in size the farther it is removed from us, for we then see it *under a smaller angle*, as it is termed; and it is found that the smallest angle under which an object can be seen, is, upon an average for different sights, the 60th part of a degree, or *one minute* in space; so that when an object is removed from the eye about 3000 times its own diameter, it will only just be distinguishable. Consequently, the greatest distance at which we can behold an object like a shilling, of an inch in diameter, is 3000 inches, or 250 feet.

"Another drawing," added Humphry, "will enable you, Kitty, readily to comprehend how an object appears to diminish in size, according as it be-



comes more and more distant from us, and so gets to be seen under a smaller angle."

"There," continued the boy, "the first arrow is seen under an angle of 120°,* whereas the angle under which the second arrow is regarded is only 60°. Consequently, though the objects are the same in size, the one will appear only $\frac{1}{2}$ the length of the other. The third arrow, again, being seen under an angle 4 times smaller, will seem to be only $\frac{1}{4}$th the size of the first; whilst the fourth arrow, for the same reason, will look as if it were only $\frac{1}{8}$th the height of the one next the eye; and the farthest arrow of all but $\frac{1}{12}$th as large as the nearest. Moreover, if we suppose another arrow still to be so far removed that the angle under which it is seen dwindles down to the 60th part of a degree, or 1′, as it is called, this will then appear so reduced in size as to be only just distinguishable to us.

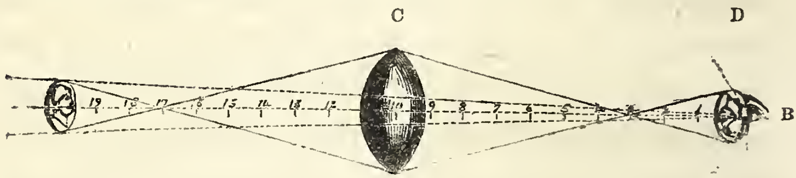
"Well, Kitty," the youth went on, "you now understand that an object appears to *diminish* in size the *farther* it is removed from us, merely because it is seen under a *lesser* angle; and, consequently, an object must seem to us, on the other hand, to *increase* in size when the image of it is brought *nearer* to the eye, and so gets to be

* The range of the eye, or diameter of the field of vision, is 110°; consequently, this is the largest angle under which an object can be seen. The largest angle, however, is here made 120°, for the simplification of the numbers. The range of vision is from 110° to 1′.

viewed under a *greater* angle. This, then, is all that lenses *really* do when they appear to magnify objects: that is to say, they do not absolutely *increase the dimensions* of the bodies under view, but merely *bring their images nearer* to the eye, and so enable us to see them under a *larger angle.* You remember I told you that, with a shilling, we can just see the king's head upon it at the distance of about 10 feet from the eye. Now, when the coin is at that distance, if a convex lens, having a focus 2½ feet long, be placed midway between the shilling and the eye, the lens will, of course, be 5 feet from the eye and 5 from the shilling; so that, in this case, it is plain, from what I before explained to you about the size of images,* that the image of the shilling seen behind the lens will be exactly of the same dimensions as the shilling itself in front of it. The object, therefore, will not have been directly magnified by the lens. The image, however, will be thus brought so near to the eye, that the coin may be seen by us at the distance of 6 inches, instead of 10 feet; and, consequently, being viewed under a proportionately larger angle, the shilling will seem to be magnified as many times as 10 feet is greater than 6 inches; or, in other words, it will be made to appear 20 times larger in our eyes. Hence the shilling will have been, apparently, magnified 20 times, merely by bringing the

* See illustration at p. 378.

image of it 20 times nearer the eye—thus. Whereupon the boy proceeded to delineate the following diagram; in which the dotted lines from the object

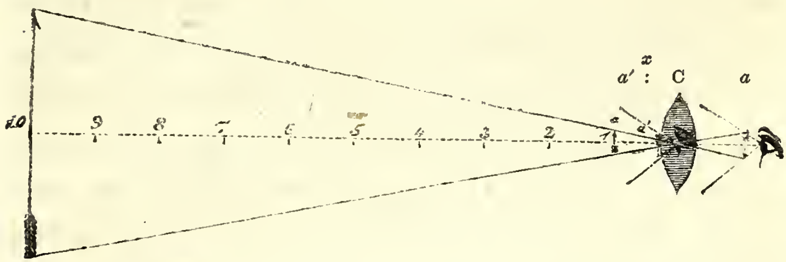


A represent the angle that the shilling itself would be viewed under without the lens, C, by the eye at B, while the dotted lines from the image D show the much larger angle that such image would be seen under with the lens.

Humphry then prepared an experiment illustrative of the apparent magnifying of objects by lenses, when their images are brought nearer to the eye. For this purpose he got Kitty to bore a hole in the shutter large enough to allow a lens to be inserted in it. Then fixing the glass in the aperture, he bade his sister close the shutters, and place her eye at about 2½ feet from the lens, for such he knew to be the length of its focus.

"How beautiful!" cried the girl, as she gazed through the transparent circle. "I see a tiny image of Madern Church; and so close, too, that I could fancy it was in the room here."

"Well," said Humphry, "the church itself, you know, is about 1½ mile distant, or, let us say, 7500 feet, and the focus of the lens is 2½ feet; consequently it follows, from what I have before told you, that the image of the church you see is 3000 times smaller than the church itself, for $\frac{7500}{2\frac{1}{2}} = 3000$. Nevertheless, if we could copy the image of the church upon a piece of paper—or, what would be better still, fix it upon a sheet of glass, we should find that, *on holding it just as far from the eye as it is now from the lens*, the tiny image that you now see would exactly cover every part of the distant object, and so appear precisely of the same size as the church itself—in this manner.



"Let us suppose the large dart, marked A here," the lad continued, as he drew the plan upon paper, "to be the height of the church, and the smaller dart, *a*, on the other side of the lens, C, to be the size of the image that we see. Well, if you were to place your eye where the lens now is, and the image just as *far in front of the glass as it now stands behind it*, it is plain, by the dotted eye and arrow at *a′*, that the one would exactly cover the other.

"Hence it is evident," added Humphry, "that the image which you see behind the lens is really of the same size as the distant object *appears* to be, even though, as in the case of Madern Church, the image is no less than 3000 times smaller than the object itself *really is.* But when you look through a glass, Kitty, the image of the distant object is only about 6 inches from your eyes; so that, though it is of the same size as the object itself *appears* to be, you are viewing it at a shorter distance than the length of the focus of the lens; and, therefore, owing to your regarding it under a greater angle, it seems to be magnified. Now, as I told you, the focus of the lens we employed was $2\frac{1}{2}$ feet, or 30 inches long; and, supposing your eye to have been where the lens was, and the image transferred to the other side of the lens (as indicated by the dotted eye and arrow marked a'), the image would have seemed exactly the same size as the object itself, provided it had been placed at a distance of 30 inches in front of you. If, however, the image had been placed only 6 inches away from your eye, it is plain that you would have been viewing it 5 times closer than $2\frac{1}{2}$ feet, and this would be the same as if the dotted arrow had been shifted from a' to x; consequently, it would then have looked to you 5 times larger than it really was, because you were regarding it under an angle 5 times greater than its own.

"The result which we come to is, therefore," concluded the youth, "that the *magnifying power* *of a lens is always equal to its focal length, divided by the distance at which the eye regards the image.* The latter, in your case, Kitty, was about 6 inches; so that the lens, having its focus 30 inches off, the magnifying power of it is arrived at in this manner: $\frac{30}{6}=5$."

Kitty asked whether it was possible to magnify an object any more than that; when Humphry told her that, had the focus of the lens he employed been longer, its magnifying power would have been greater; "as for instance," said he, "if the length of the focus had been 5 feet, instead of $2\frac{1}{2}$, it would have magnified 10 times instead of only 5, for $\frac{60 \text{ inches}}{6 \text{ inches}}=10$. So, again, had the focus of the lens been 10 feet, its magnifying power would have been doubled again, for $\frac{120 \text{ inches}}{6 \text{ inches}}=20$. But," continued the boy, "the magnifying power might be increased in another way—namely, by bringing the eye nearer to the image. As yet we have estimated the distance at which the eye views the image produced by the lens at 6 inches, because that is the length at which we see near objects distinctly. Hold your finger before your eye, Kitty, and you will see that when you bring it very close you can scarcely distinguish it. With a lens, however, having a short focus, you would be able to see the finger much nearer than naturally; and then, for the reason I have before given you, it would appear to be as much magnified as the distance at which you beheld it distinctly *with* the lens was less than 6 inches, which is the distance at which you beheld it distinctly *without* the lens. In my cupboard you will find a burning-glass, and that has a focus of only 2 inches. Do you get it, Kitty, and look at your finger through it."

The girl did as she was bidden, and immediately cried, "Oh, Humphry! what a horribly ugly, coarse, thick-looking thing it is! Why, I declare my skin looks like an elephant's hide through it; and I can see every line in it, like the veins on a leaf!"

"Yes," returned her brother, "that is because you are now looking at your finger 3 times nearer than you could see it distinctly without the lens, and, consequently, you behold it under a proportionately larger angle; so that it appears to you to be 3 times magnified—for $\frac{6 \text{ inches}}{2 \text{ inches}} = 3$. Let us then apply the same principle to the image of Madern Church as seen through the lens in the shutter, and which, you remember, appeared to be magnified 5 times, because you saw it at 6 inches from your eye instead of 30 inches, which was the focal length of the lens. But now, by means of this burning-glass held near your eye, do you look at the image once more, and tell me, Kitty, what you see."

The shutters were accordingly closed again, and the girl proceeded to take another peep at the distant church through the two lenses.

"Oh, Humphry!" she cried, "I see it much plainer than ever; and it is, as you say, a great deal bigger, too."

"Of course it is," returned the brother, "for the length of the focus of the burning-glass is, as I said, 2 inches; so that you now see the image of the church at that distance from your eye, instead of 6 inches, as before. The image, therefore, appears to be magnified 5 times by the first lens, and 3 times by the second, or $5 \times 3 = 15$ times in all; and the reason of its appearing to be that number of times larger to you, is simply because you are looking at it at 15 times a shorter distance than the focal length of the lens in the shutter, which is called the 'object-glass,' and so seeing it by means of the other lens, which is called the 'eye-glass,' *under* 15 *times a greater angle than you behold the object itself with your naked eye.*"

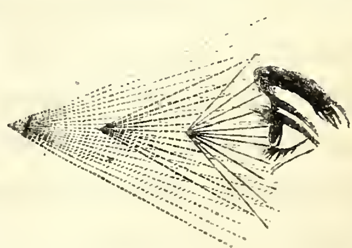
"I understand it now perfectly, Humphry, thank you," said the sister, pleased with the explanation. "And are the telescopes that the sailors use made upon the same principle?"

"Precisely so, Kitty," responded the brother. "And in order to find out the magnifying power of any of these, we have merely to *divide the length of the focus of the object-glass by that of the eye-glass, and the quotient will tell us how many times* *the objects are enlarged by them;* whilst in order to make a telescope for ourselves, we have merely to procure a lens of a long focus—say 12 inches, and one of a short focus—say 2 inches, and then to set these in a tube at the length of the two foci, or 12+2=14 inches apart. This tube, however, should be a sliding one, so as to admit of the distance between the two lenses being increased according as the objects viewed are nearer at hand; for I told you before, you remember, that the *nearer* the object the *farther* is the image from the lens, and *vice versâ*, the more *distant* the object, the *shorter* the focus of the glass becomes."*

* The arrangement of lenses, above described, constitutes the principle of what is termed the "*astronomical* telescope;" for this makes the objects appear upside down. But, though the inversion of a star or planet is a matter of no moment in astronomical observation, such an effect is most disagreeable when applied to terrestrial objects. The ordinary telescope for *land* purposes, therefore—or the "*day* telescope," as it is usually styled—has two other lenses behind the eye-lens. These lenses have both the same focus as the eye-lens itself, and are placed at a fixed distance from each other, such distance being equal to the sum of their focal lengths: that is to say, if the eye-lens have a focus of 2 inches, then each of the two other glasses should have the same length of focus, and be placed at 4 (2+2) inches apart from one another. The magnifying power of the day telescope may be calculated in the same manner as that of the astronomical one above explained; for the two additional lenses in the day instruments, having the same focal length as the eye-lens itself, produce no further enlargement of the objects, but serve only to *cross* the rays a second time, and so to render the image *erect* instead of *inverted*.

Now that Kitty understood the principle upon which telescopes were constructed, she begged her brother to promise to construct one as soon as he was well; and Humphry having consented, the two then passed on to the consideration of the principle of the *microscope*.

"I have already told you," said Humphry, on entering upon the subject, "that the nearer an object comes to us, the larger it appears. But, as you saw, when you held your finger close before your eye, it grew so indistinct and confused, that the form of it was almost as obscure as if it had been at a great distance from you. Now this effect is produced by the greater divergence of the rays of light, whenever an object is brought nearer to us; and when the divergence is very great, the crystalline lens within the eye has not power to collect the rays into a focus on the retina at the back of the eyeball. You will understand how the rays come to diverge more and more the nearer an object approaches to us, by the following illustration.



"There, we will suppose the eye to be looking at some very minute object, like a speck of the dust from a butterfly's wing, at the distance of 6 inches, 4 inches, and 2 inches. Well, at 6 inches, the rays of light given off by it, you perceive, diverge but slightly in comparison with the angle at which they enter the eye at 2 inches. Consequently, the image produced within the eye itself would, in the latter case, be so dim that we should be almost unable to distinguish it. In order, however, to look at a very small object, we must bring it as close as possible to the eye; so that, to enable us to see it *distinctly* at a short distance, we must find out some means of *decreasing the divergence* of the rays of light from near objects—or, what would be better still, of making the rays enter the pupil in *parallel* lines.

"Now I showed you, a short while back, that a convex lens causes the rays of light from objects placed in its focus to pass out on the other side of the glass parallel to each other. Consequently you perceive that, by means of a double convex glass, we can see objects distinctly when held at $\frac{1}{2}$ an inch—or even the $\frac{1}{10}$th of an inch—from our eye, provided such be the focal length of the lens employed; and thus we shall, for the reasons before explained, obtain a *magnifying power which will be equal to the distance at which the naked eye can see minute objects distinctly divided by the focal length of the lens employed.* For example, the distance of distinct vision for very minute objects may be taken at 5 inches, so that if we make use of a lens having a focus of 1 inch, the magnifying power will be equal to 5 inches divided by 1; that is to say, an object viewed with such a glass will appear to have its length and breadth increased five-fold; so that its *length* being magnified 5 times, and its *breadth* 5 times also, its *entire surface* will be increased as much as 25 times, or 5×5. If, however, we employ a lens having a focus of only $\frac{1}{10}$th of an inch, the *linear* magnifying power will be equal to 5 inches divided by $\frac{1}{10}$ (or $\frac{50}{1}$), that is to say, to 50-fold; while the *superficial* magnifying power will amount to 50×50, or 2500-fold; and if, again," went on the lad, "the lens employed have a focus of only $\frac{1}{100}$th of an inch, then the *linear* magnifying power will be equal to 5 inches divided by $\frac{1}{100}$th (or $\frac{500}{1}$),—that is to say, to 500, and the *superficial* magnifying power to 500×500, or 250,000.

"A lens of a very short focus," added Humphry, "constitutes what is termed the *single microscope*. For this purpose the lens is usually made spherical, —as a sphere, or round ball of glass, has its focus at a distance from its centre equal to $1\frac{1}{2}$ its own *radius;* so that if we had a small glass ball, of 1 inch in diameter, the focus of such a lens would fall at $\frac{3}{4}$ths of an inch from the centre of the ball itself; whereas if the ball was $\frac{1}{4}$th of an inch in diameter, it would have the focus at $\frac{3}{16}$ths of an inch from its centre: so that you will readily comprehend, Kitty, how tiny a sphere must be used in order to give great magnifying power with a single microscope. To have a lens of $\frac{1}{10}$th of an inch focus that will, consequently, be able to magnify an object 50 times in length and breadth, it would require the glass sphere to be only about $\frac{13}{100}$ths of an inch in diameter. The perfect execution of such lenses requires considerable skill in the grinding and polishing, therefore other means of constructing them have been desired. One simple method of forming a microscopic lens consists in drawing out (by means of a spirit-lamp) a thin strip of window-glass into threads, and holding the end of one of such threads in the flame until it runs into a globule. The globule is then cut off and set in a small aperture, in such a manner that none of the rays may pass through that part of the tiny ball where it was originally united to the thread. Another process," continued the youth, "consists in taking up some fine-pounded glass on the wetted point of a needle, and then melting it by a spirit-lamp into a globule, after which the globule is removed, and once more taken up, by the wetted point of the needle, on its round side, when it is again inserted in the flame, until it becomes a perfect sphere. Moreover, drops of water, as well as drops of oil or varnish, have been used for microscopic lenses. These are placed on a small piece of plate glass, and have considerable magnifying powers. Further, the lenses from the eyes of fish have been used for the same purpose; but, in this case, it is necessary to look through the lens in the direction of its axis—or, in other words, in the same manner as the fish did.*

"A good *extempore* microscope may be formed out of two test-tubes filled with water, and placed one across the other, like the algebraic sign +."

To please his sister, Humphry had his spirit-lamp lighted, and proceeded to form some little globules of glass in the flame, in the manner before explained; and then, having set these upon a plate of brass, he showed the delighted girl how wonderfully objects were magnified by them; and afterwards he went on to explain to her how it was possible to

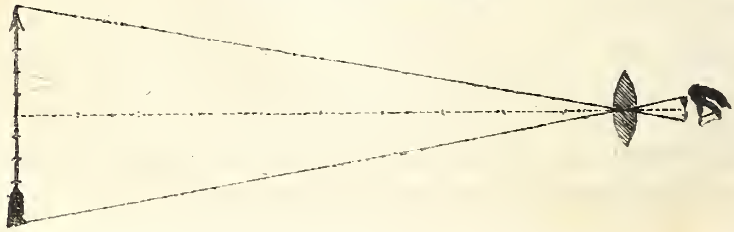
* Within the last 30 years the diamond has been used for the purpose of microscopic lenses; for, owing to the refractive power of this precious stone being greater than almost any other known substance, and nearly double that of glass, lenses can be produced from it of a great degree of magnifying power, and that with a comparatively small curvature, so that increased distinctness is obtained; while the lens itself, being nearly "*achromatic*," the image produced by it is untinged by prismatic colours. Mr. Pritchard constructed the first diamond microscope in 1826. The diamond lens of this was double convex, and had a focus of $\frac{1}{30}$th of an inch, so that its magnifying power was 150 times. Dr. Goring, an eminent authority on the subject, says—"I conceive diamond lenses to constitute the ultimatum of perfection in the single microscope." The sapphire has also been used for the construction of microscopic lenses with considerable advantage, its magnifying power being much greater than that of glass. Mr. Pritchard says, that the sapphire, next to the diamond, possesses all qualities requisite for the formation of a perfect magnifier, and presents less difficulties in the construction.

increase the microscopic power of lenses, even without diminishing their size.

"Suppose," said he, "that we have a lens of ½ an inch focus, and which would, therefore, magnify the diameter of objects 10 times; and then suppose that, instead of looking directly at the image, we place another lens of a short focus—say 1 inch—between it and our eye, and so view the image through the second lens. Well, this second lens would, for the reasons before given, magnify the object 5 times more; so that it would thus be made to appear 50 times bigger in all, the image being rendered ten times greater by the first lens, and that image, again, 5 times greater by the second. This constitutes what is termed the *compound microscope*; and, by means of this instrument, objects may be magnified to almost any extent."

Humphry having now thoroughly made out to himself, as well as his sister, the principle upon which the power of the *microscope* and *telescope* depends, concluded the subject by drawing the following diagrams, illustrative of the opposite action of the two instruments:

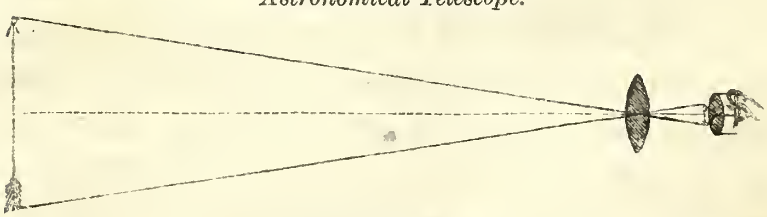
Telescopic arrangement.



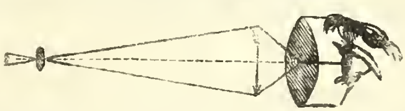
Microscopic arrangement.

"There," said the boy, "in the one case, as in the preceding diagram, the *object* is at a considerable *distance* from the lens, and the *image near* it; while in the other, as in the above diagram, the *object* is *near* the lens, and the image at a considerable *distance* from it. Now if we suppose, Kitty, the object to be 10,000 feet in front of the first lens, and the image 10 feet behind it, it follows that the image, in this case, would be 1000 times smaller than the object itself; and if we suppose, on the other hand, the object to be $\frac{1}{100}$th of an inch in front of the second lens, and the image to be 10 inches behind it, then the image, in that case, would be 1000 times larger than the object itself. Let us now imagine another lens to

Astronomical Telescope.



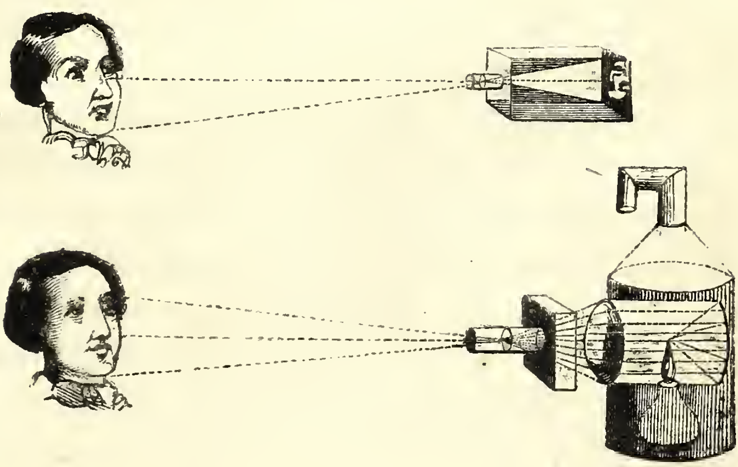
Compound Microscope.



be placed before each of the images—as here shown—so that the eye may view them at a shorter distance than it could see them distinctly without any such aid; and let us say, again, that the focal length of this second lens is, in both cases, 1 inch. Well, then, we should be regarding the image in the upper diagram at a distance of 1 inch instead of 10 feet, which is the focal length of the object-glass, and so bringing it 100 times nearer to our eye; the consequence would be, that it would appear to us to be 100 times larger than it would at the distance of 10,000 feet, so that this would be the magnifying power of the instrument, which, as I said before, is always *equal to the focal length of the object-glass, divided by that of the eye-glass.* Such, then, constitutes the arrangement of the astronomical telescope. In the compound microscope, however," added Humphry, "the magnifying power is estimated by *multiplying* instead of *dividing* the power of the object-glass by that of the eye-glass; so that, as we supposed the first lens in the lower diagram to magnify the object 1000 times, and the second lens now enables us to view the image distinctly at 5 times nearer the eye than we could without it, the gross magnifying power, therefore, must amount to no less than 1000×5, or 5000 times."

The youth then went on to explain to his sister that the same relation which exists between the telescope and the microscope, also holds good between the *camera-obscura* and the *magic-lantern.* In the camera-obscura, for instance, the object, as in the telescope, is at a considerable distance in front of the object-glass, and the image at a short distance behind it; whereas in the magic-lantern, the object, as in the microscope, is at a short distance in front of the object-glass, and the image at a considerable distance behind it. In the camera, therefore, the image is as much diminished as it is *nearer* the lens than the object; whilst in the magic-lantern the image is as much magnified as it is *farther* from the lens than the object.

The annexed drawing will illustrate the action of these two instruments clearer than words can describe them:



The reader has only to suppose the image produced by the camera—a portrait, let us say—to be fixed upon glass (by the "collodion process" of photography, an invention since Davy's time), and this image to be made to serve as the object (or, in plainer language, the slide) of the magic-lantern, in order to comprehend how the object in the one instrument may be made the image in the other, and *vice versâ*, the image of the first the object of the second.

CHAPTER XVI.

THE WONDERS OF THE REFLEXION OF LIGHT.

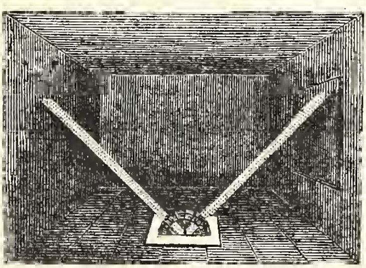
Hitherto Humphry had considered only the laws which regulate the transmission of light through transparent bodies. This constitutes the branch of the subject called *dioptrics* (from *δια*, through, and *οπτομαι*, to see). The other branch, termed *catoptrics* (from *κατα*, from, or against, and *οπτομαι*, to see), deals with the laws of light when it is reflected or thrown back from the surface of any body *against* which it falls. Accordingly the lad passed, in due order, from the *transmission* to the *reflexion* of the luminous rays.

To explain this part of the subject the youth first procured a piece of an old looking-glass, and having got Kitty to close the shutters once more, he placed the looking-glass upon the ground, so that the ray might fall just in the middle of it; when, as the room was thoroughly darkened, it was easy to observe the inclination, or angle, at which the light fell on the reflector, as well as to perceive the course it took afterwards.

"Why, I declare," cried Kitty, as she looked at the bright streak, "it goes down and then up again; and I can see the beam slanting away from the glass on each side, for all the world like a big letter V!"

"Yes," returned Humphry, "you see the course of the beam is stopped by the looking-glass, and instead of going through it, the thread of light that streams *down* from the hole in the shutter no sooner falls on the mirror than it is driven up from it, precisely in the same manner as if the luminous particles were a series of hard balls projected against the glass, and so made to bound off from its surface."

The youth then called for his arc, and proceeded to measure the angle at which the light fell upon the glass, and also the angle at which it was reflected from it—thus:

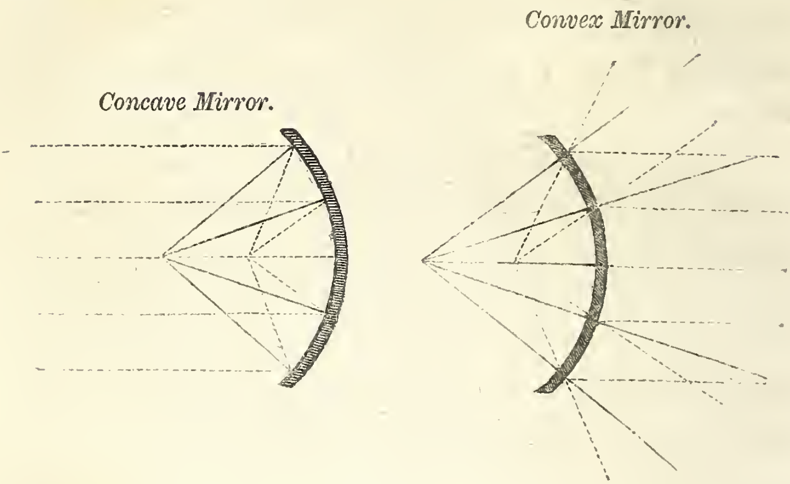


"Do you see, Kitty," he cried, as the eager girl stooped down beside her brother, "the ray that slants down from the shutter falls upon the glass at an angle of 45°, and this is what is called the angle of *incidence;* while the ray which slants upwards from it is reflected from the glass at 45° also, and this is what is called the angle of *reflexion:* so that, you perceive, *the one is exactly equal to the other, and this constitutes what is termed the law of reflexion.* For, no matter what the form of the mirror itself, or in what direction a ray of light falls upon it, it is always reflected or driven back from the surface at precisely the same angle as it strikes upon it. As you say, the two rays form a kind of letter V, and one prong of the letter always slants just as much as the other."

"But suppose the surface of the glass, Humphry, was to be hollowed out like a bowl, would it do so then?" inquired the girl.

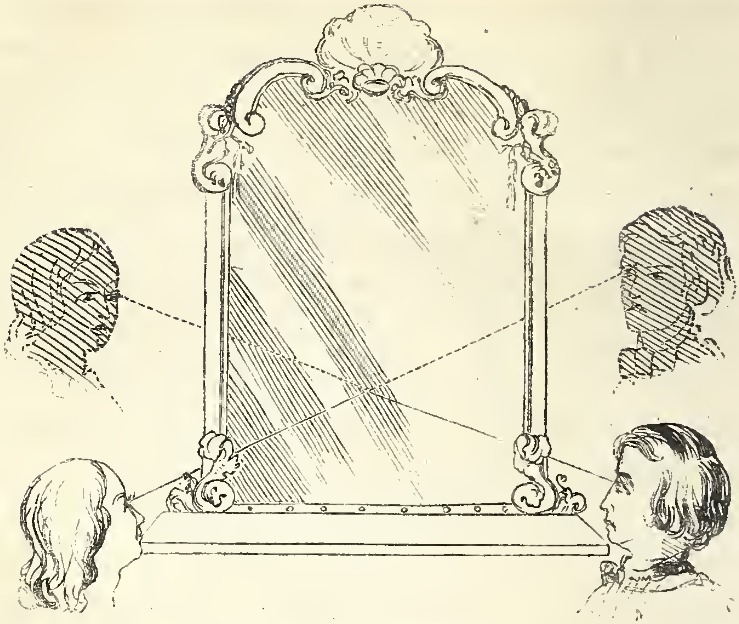
"Certainly," was the reply; "and if the rays falling upon it then were parallel one to the other, you would find, upon drawing the figure on paper, that they would all meet together at one point in front of the glass, which would, consequently, be the focus—*the distance of such focus being equal to half the radius, or semi-diameter, of the curvature of the mirror itself.* Give me the compasses and open the shutters, Kitty, and you shall soon see what I mean."

In a few minutes the following diagram was described:

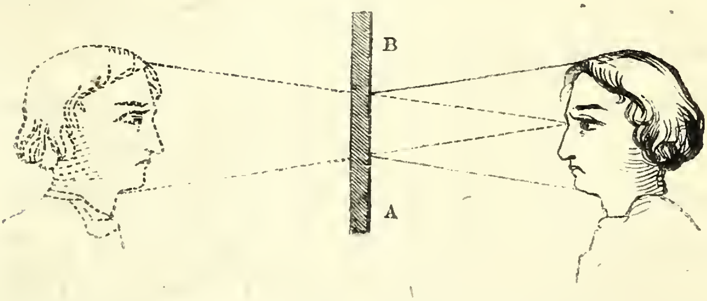


"There!" cried Humphry, as he put the last touch to the drawing, "the two curved lines represent the surfaces of a *convex* and a *concave* mirror, the curvatures of which form portions of a circle, having its centre at the point where the unbroken lines meet. Now, these unbroken lines, being drawn in each case from the centre to the surface of the mirror itself, are exactly perpendicular to the points where the rays of light fall; and if you measure with the arc the angle which the dotted parallel lines form on one side of the unbroken ones, you will find that they are, in every case, here equal to that which the dotted slanting lines form on the other side of the same perpendicular. Consequently, you perceive that, by a concave mirror, the rays are made to *converge* to a focus in front of the mirror itself; whereas by a convex mirror the rays are made to *diverge*, as if they came from a focus behind the mirror itself. Now this, you remember, is precisely the same as what takes place with concave and convex lenses; for a concave lens has its focus in front of it, like a concave mirror, but, owing to the rays passing *through* the lens in the one case, and being driven back *from* the mirror in the other, they are made by the lens to *diverge* and by the mirror to *converge.* So that, while the concave lens *diminishes* the apparent size of objects, the concave mirror *magnifies* them. The same thing holds good," continued the boy, "with a convex lens and a convex mirror; they both have their focus behind them, but the rays, in passing *through* the lens, *converge* to a point, whereas, being driven *back* from the mirror, they *diverge;* and so, while the convex lens *magnifies*, the mirror *diminishes* the apparent size of objects."

Next, Humphry directed his sister to place herself alongside the looking-glass over the mantelpiece, while he did the same facing her, and in such a manner that neither could see their own figure reflected in the mirror. It would then be found, he said, that they would each behold the other, and at exactly the same distance behind the glass as they were in front of it. In this manner:

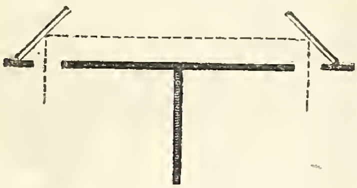


"Now the reason why I see you," said the lad, "and you see me in another place than we really occupy, is, because the rays reflected by the glass enter our eyes in that direction; and, as I told you before, *an object is always seen by us in the direction which the ray has at the moment of reaching the eye, without regard to what may have been its course previously.* Your image, of course, Kitty, is *on* the surface of the glass itself, and not *behind* it, as it appears to you to be; and what, I dare say, will sound stranger to you, is, that the image itself upon the glass is exactly half the size that it seems to be behind it: for since, when you look at yourself in the glass, your image appears to be just as far at the back as you are standing in front of the mirror, it is evident that the mirror itself must be half-way between you and your apparent image; so that it will cut in half the cone of rays which enter your eye from the surface of the looking-glass.



"There is a picture," continued Humphry, as he put the drawing before his sister, "of a person looking at himself in the glass; and you will see, by the rays from his chin and forehead, which are reflected in a point to the eye, that a vertical line A . . . B, at the surface of the glass, must be exactly equal to half the length of the image, since the image and the eye of the spectator are always at equal distances from the glass itself. But the image, which *appears* to be behind the glass, is seen under the same angle as the image, which is *really* on the surface of it; and so, for the reasons I before gave you, when speaking of the apparent size of objects in general, the one behind the glass appearing to be at twice the distance of the other, naturally seems to be twice as large as the image on the surface really is.

"I have already shown you, Kitty," went on the youth, after a pause, "that if two persons stand in front of a mirror, and each at opposite sides to it, they will see one another, but not themselves; and this constitutes the principle of what is termed the 'magician's mirror.'



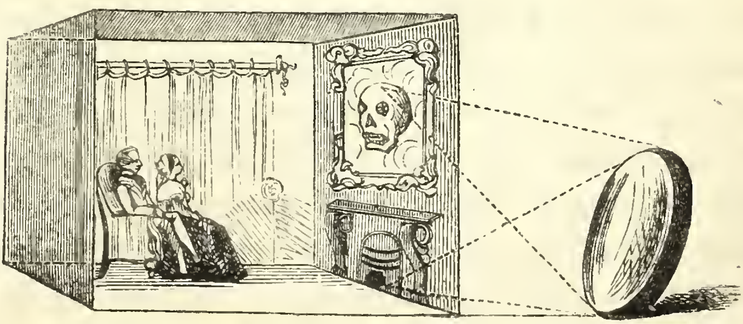
"Here is a plan," said Humphry, "of the ordinary arrangement. The black lines we will suppose to represent the walls of two adjoining apartments. At the end of each of the rooms there is an aperture, made large enough to place behind it a looking-glass that is capable of reflecting the whole figure. In each of these apertures there is inserted a sheet of plate-glass, which is surrounded with a gilt frame, so as to have the appearance of an ordinary mirror; and behind this a real looking-glass is placed, slanting at an angle of 45°, and so large, that a person looking into the sheet of plate-glass cannot see the edges of the slanting mirror behind it. With such an arrangement, it is plain that a person looking into either of the mirrors will not see himself, but any one who may chance to be looking at the same time into the mirror in the adjoining room. Consequently, on looking into the mirror and believing that he should see his own figure reflected in it as in an ordinary looking glass, his astonishment will be great in beholding himself transformed into another person, or, indeed, into some living animal that may be placed in front of the neighbouring glass."

Kitty observed to her brother, that she remembered having seen the same kind of an apparatus in a booth in a fair; and by it persons were said to be shown their future lovers.

Humphry told her that it was by the same means that people were made to see, apparently, through paving-stones.

"For if," said the boy, "by the arrangement I have explained to you, it is possible to see a figure in another apartment—a brick wall intervening—it is obvious that, by the same device, an object placed on one side of a paving-stone could be readily seen on the other.

"But the concave mirror," continued Humphry, "is capable of producing far more wonderful effects, for the image from this appears suspended in the air; so that if the mirror and the object are hidden from view, the effect is almost supernatural. This illustration represents the arrangement usually employed in such cases—



"Here you perceive, Kitty," added the lad, "the two sides of a room, at the end of which there is a square opening, with a picture-frame surrounding it. Outside the room, in an adjoining apartment, is placed a large concave mirror; and so arranged, that when an object is set a little above the floor in front of it, a distinct image of it may be formed in the centre of the aperture at the end of the room, where the spectators are assembled. Now, if the opening be filled with smoke, that is made to rise in clouds from a chafing-dish concealed outside, the image of any object placed in the one focus of the mirror in the adjoining apartment will appear in the other focus at the centre of the frame, and seem to be depicted on the clouds of smoke there as a back-ground. It is a favourite experiment to place a skull, strongly illuminated, in the outer apartment, and to reflect an image of it amid the smoke, so as to be visible to the spectators in the inner room. The trick of the mysterious dagger, too, is very popular. The ordinary way of performing this is by placing a basket of fruit in the one focus of the mirror, so that a distinct aërial image may be formed of it in the frame. One of the spectators is then desired to take some fruit from the basket; and as he approaches for that purpose, a person, properly concealed, withdraws the real basket of fruit with one hand, and with the other substitutes a dagger, the image of which seems to strike at the body of the spectator, and the thrust of the bright polished steel at his breast never fails to produce a powerful impression. Now, it can scarcely be doubted that a concave mirror was the principal instrument by which the heathen gods were made to appear in the ancient temples. Jamblichus informs us, that the ancient magicians made the gods visible to the people among clouds of incense. And in the middle ages the Pontiff, Theodore Santabaren, who was celebrated for his power in working miracles, exhibited to the Emperor Basil of Macedonia the image of his lost son, magnificently dressed, and mounted on a superb charger. The apparition of the youth seemed to rush towards his father; and, throwing himself into his arms, vanished. This effect was doubtlessly produced by reflecting the image of a picture of the emperor's son on horseback; and the picture being brought nearer to the mirror, the image, of course, appeared to advance until it reached the emperor's arms, where it naturally eluded his grasp. The celebrated Benvenuto Cellini has left us an account of a more modern necromancy, in which he himself took a part, in the middle of the sixteenth century.

"'It happens,' says Cellini, proceeded Humphry, as he read the account to his sister, 'through a variety of odd accidents, that I made acquaintance with a Sicilian priest, who was a man of genius, and well versed in the Latin and Greek authors. Chancing one day to have some conversation with him, when the subject turned upon the art of necromancy, I, who had a great desire to know something of the matter, told him that I had all my life felt a curiosity to be acquainted with the mysteries of the art. The priest made answer, that the man must be of a resolute and steady temper who enters upon that study. I replied, that I had fortitude and resolution enough, if I could but find an opportunity. The priest subjoined, 'If you think you have the heart to venture, I will give you all the satisfaction you can desire.' Thus we agreed to enter upon a plan of necromancy. The priest, one evening, prepared to satisfy me, and desired me to look out for a companion or two. I invited one Vincenzio Romoli, who was my intimate acquaintance; and he brought another with him. We repaired to the Coliseum; and the priest, according to the custom of necromancers, began to draw circles upon the ground, with the most impressive ceremonies imaginable. He likewise brought hither asafœtida, several precious perfumes and fire, with some compositions also, which diffused noisome vapours. As soon as he was in readiness, he made an opening to the circle; and having taken us by the hand, ordered the other necromancer, his partner, to throw the perfumes into the fire at a proper time, entrusting the care of the fire and the perfumes to the rest; and thus he began his incantations. This ceremony lasted above an hour and a half, when there appeared several legions of devils, insomuch that the amphitheatre was quite filled with them.' Cellini afterwards tells us, 'that the necromancer called by their names a multitude of demons, who were the leaders of the several legions, and questioned them by the power of the eternal, uncreated God, who lives for ever, in the Hebrew language, and likewise in Latin and Greek, and then the amphitheatre was almost in an instant filled with demons, more numerous than at the former conjuration. The necromancer requested me to stand resolutely by him, because the legions were now above a thousand more in number than he had designed; and, besides, these were the most dangerous. The boy who had accompanied us was in a terrible fright, saying that there were in that place a million of fierce men, who threatened to destroy us; and that, moreover, four armed giants of enormous stature were endeavouring to break into our circle. Vincenzio Romoli quivered like an aspen leaf. Though I was as much terrified as any, I did my utmost to conceal the terror I felt; so that I greatly contributed to inspire the rest with resolution. But the truth is, I inwardly gave myself over as a dead man. The boy placed his head between his knees, and said, 'In this posture will I die, for we shall all surely perish.' In this condition, concludes Benvenuto, we stayed till the bell rang for morning prayers.' "

CHAPTER XVII.

THE WONDERS OF COLOUR AND PHOTOGRAPHY.

The young philosopher had now completed his investigations concerning the refraction and reflexion of light. He had ascertained—

1. That all substances in nature are divisible into two classes, viz. *luminous* and *non-luminous* bodies.

2. That *luminous* bodies send off rays of light from them *in all directions*, and that such rays proceed in *straight* lines while traversing the same medium.

3. That *non-luminous* bodies are *transparent*, or *opaque*; that is to say, they either allow the rays of light emitted by luminous bodies to pass through them, or else they arrest their progress; sometimes, in the latter case, driving them off from their surfaces, and sometimes absorbing them.

4. That when a ray of light falls obliquely on a transparent body it is, on entering it, refracted or

bent, in a greater or less degree, out of its previous straight course.

5. That when a ray of light is driven off or reflected from opaque (or even transparent) bodies, the angle of reflexion is invariably equal to the angle at which the ray falls upon their surfaces.

As yet, however, Humphry had dealt only with white or ordinary uncoloured light, and he was now about to study the phenomena of colour itself—to investigate the laws which regulate the production of the varied tints on the earth, and to ascertain, if possible, the means by which the soil is painted with a thousand hues, and how the colourless sunbeam becomes broken up into countless dyes as it falls upon the flowers and the rocks, and is driven back by them to the eye, arrayed in all the charm of variegated lustre.

"How comes it," said Humphry to himself, as he thought over the subject, "that the earth by night is black and sombre, as if a pall were spread over the dead globe—that the trees have then a dim, spectral look—that the sky is dusky as a canopy of smoke, and that the buildings seem like masses of dense shadow darkening the air, so that the world about us is as colourless as a cavern, and the beauty of surrounding nature blotted out with the universal gloom? And how is it, too," mused the poetic boy, "that the beams of the returning sun have power to dye the fields and sky with the richest hues—to crimson the clouds with the glowing tints of dawn, and to revive, as it were, in an instant, the infinite colours of the flowers, so that the ground grows suddenly iridescent with their various dyes? How comes it, again, that at the tropics, where the sun steeps the earth in a flood of light, the plumage of the birds and the blossoms of the plants are unrivalled for the gorgeousness of their colours; and that as we proceed thence to colder climates we find a regularly declining chromatic scale, the tints becoming less and less vivid till we reach the Poles, where Nature is arrayed in one unvarying robe of white?"

But Humphry was too anxious to experiment to continue dreaming over the matter, and, accordingly, he got his sister to darken the room once more, and then attaching a prism in front of the hole in the shutter, he proceeded to throw the spectrum on the wall in the manner before described.

Kitty was as delighted as the boy with the beauty of the image, nor could she help wondering how it happened that a simple stick of white glass could resolve the sunbeam into such exquisite tints.

Humphry told her that the image she saw on the wall was merely an oblong picture of the sun itself, the orb being drawn out to that figure by the refraction of the glass. The vividness of the colours depends upon the smallness of the aperture through which the light is admitted, and the distance of the screen upon which the spectrum is made to fall; so that if the hole in the shutter were smaller, and the wall farther off, the spectrum would be much brighter. The colours, he added, came from the decomposition of the sunbeam into its elementary tints.

"You, doubtless, Kitty, think the light of the sun to be simple and uncompounded, and little dream that every ray of white light which meets your eye is made up of seven other beams, and each coloured with some one of the tints you see in the spectrum here; and it is solely because the sunbeam is a *compound* rather than a simple thing, and that each of the seven rays of which it is composed have different properties and refrangibilities, that this glass prism has the power of separating them one from the other, and so of resolving the compound beam into its seven elementary rays. Look here," he continued; "were it not for this prism the beam which comes through the hole in the shutter would proceed in its previous course, and strike upon the floor; but by means of this instrument it is *refracted*, or bent out of its path, and as the coloured beams of which it is composed are, as I said, all differently refrangible, the red ray here, being the least refrangible of all, is the least bent out of its course, and so made to appear at the bottom of the spectrum; whereas the violet ray, which is the most refrangible, undergoes the most deviation, and thus is found at the upper part of the coloured image."

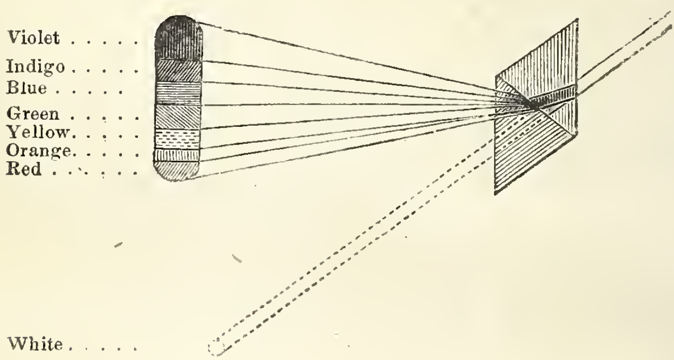
Kitty acknowledged that it was beyond her power to comprehend how a beam of white light, which appeared to her to be devoid of all colour whatever, could be *really* composed of every kind of colour. "How was it possible," she said, "for violet, and blue, and green, and yellow, and red, when mixed together, to form white?"

Humphry smiled at his sister's incredulity, and said he would show her that it was quite possible to put the parts of the sunbeam together again—for by the same means as he had decomposed the white beam into its seven coloured rays, so would he compound those seven coloured rays again into one colourless beam.

The girl was all eagerness to see the composite nature of light thus practically demonstrated, and in obedience to her brother's instructions she proceeded to place a sheet of white pasteboard against the wall, so that the spectrum might fall upon it, and then to bring it gradually nearer the prism.

As Kitty did this, she noticed that the spectrum grew smaller and dimmer; but though the colours began to mix and encroach upon one another as she advanced towards the prism, she found that, even when the pasteboard screen was brought close to the face of the glass she could still recognise the separation of the light into its elementary coloured beams.

This done, Humphry proceeded to annex to the prism already employed another, which was exactly similar in all respects—being made of the like kind of glass, and having a like refracting angle—to the previous one. The second prism, however, was placed in the opposite direction to the first, so that while the base of the one was uppermost, that of the other was underneath—as here shown:



The reason of this arrangement was, as Humphry explained, that the second prism might exactly undo what the first had previously done, so that the rays being now refracted by the one in an opposite direction to the other, they would be all brought together again, and made to strike upon the same spot as they would have fallen upon had no such instruments been interposed.

The apparatus being fixed, the ray from the hole in the window-shutter no sooner passed through the two prisms than the coloured spectrum which the beam had been previously resolved into vanished from the wall, and a round white spot of light appeared upon the floor.

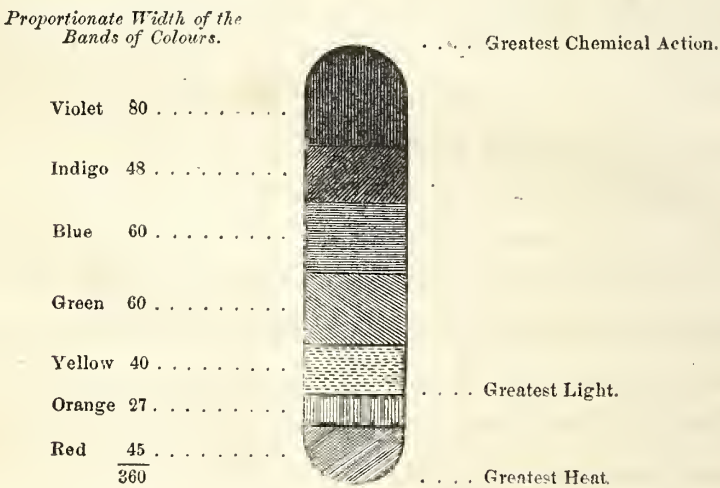
Kitty was so wonder-stricken at what she saw, that she looked at Humphry with the same fixed stare as a child gazes at some parlour magician.

"You see, then, sister," said the lad, "that seven coloured rays may be compounded again into one white one, even as one white beam can be decompounded into seven coloured ones. So that, incredible as it may seem to you, it is impossible to avoid the conclusion that white light is a *composite* thing, and made up of a number of other kinds of light that are widely different from it. But," continued Humphry, "there is another and simpler means of proving this point to you."

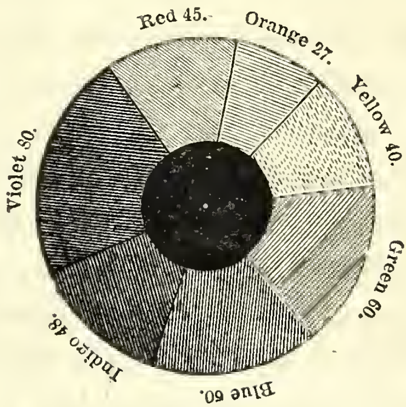
For this purpose the girl had to procure from the colour-shop seven different colours in powder, each of the same tint as one of the rays in the spectrum. These were afterwards mixed in the same proportion as the rays themselves bore to one another, and, to Kitty's astonishment, the result was a kind of *greyish white*, produced by the mingling of the whole; and Humphry told her that, were it possible to obtain colours of precisely the same tint as those in the spectrum, a perfect white would be the consequence.

"Again," the youth continued, "if we take a circle, and paint round it the several prismatic tints in the same proportion as they exist in the spectrum itself, and cause these to revolve so rapidly that the eye is unable to see any *one of them*, but rather perceives the whole at once, the paper will no longer appear coloured like the rainbow to us, but seem really white as it flashes past the eye."

It was necessary, however, before doing this, to measure the several lengths of the coloured spaces in the spectrum itself, when it was found that the various prismatic tints were in the proportions hereunder given:



The next step was to colour a circular piece of paper, as nearly as possible in the same manner as the spectrum, and this was done after the following fashion—where it will be seen that the outer coloured circle is nothing more than the prismatic spectrum bent round till its two ends meet at the point between the violet and red—the entire circle itself being supposed to be divided into 360 parts.



The circular spectrum, when finished, was placed upon a humming-top, and the top being made to spin as rapidly as possible, the prismatic disc, as it whirled past the eye, appeared to be absolutely colourless; for each tint as it revolved left its impression upon the retina but for an instant, and this being immediately afterwards covered by the tint which was next to it, the result naturally was, that the whole of the seven colours fell upon precisely the same part of the retina itself, and so produced a composite impression—the seven coloured rays being perceived all at once, rather than one after another. Hence the circle seemed to be devoid of any *one* of the colours painted upon it, and to partake of that white tint which naturally results from the blending of the whole.

Humphry himself was almost as delighted as his sister with the result of his experiments. It was demonstrable that the light of the sun which fills the air by day, and seems absolutely colourless to us, is not of that simple homogeneous nature which we are naturally led to believe, but really made up of *seven* coloured rays, which the eye itself is unable to separate, and from which proceed all the several hues with which the earth is painted, for the composite white beam falling upon the different objects around is broken up by them into its elementary tints, and some one of these reflected by them to us, so that the object itself naturally appears of the same colour as the beam it sends to the eye.

Humphry had now to investigate the several properties of the spectrum itself.

It will be remembered that he before found the point of greatest *heat* to exist at the very extremity of the red ray, and he now ascertained by means of a *photometer* (or an instrument for measuring the relative intensity of different lights) that the point of *greatest light* existed at the boundary of the orange and the yellow rays. Consequently, as the red (or calorific) rays were less refrangible than the yellow (or luminous) rays, there was but one conclusion to come to — *light was itself more refrangible than* *heat;* that is to say, the light in passing through the prism, and being there separated from the heat with which it was previously associated, was bent farther out of its course than the heat was, so that the two principles were differently acted upon by the glass, and consequently possess different powers and susceptibilities.

"But if," said Humphry, "the red rays are the calorific ones, and the yellow rays the luminous ones, what peculiar properties belong to the rays at the upper end of the spectrum, where the sunbeam is bent the farthest of all out of its previous course? What special power appertains to the violet and blue portion of the coloured image?"

The youth knew, from the books he had studied upon the subject, that these constituted the chemical beams—that is to say, the violet extremity of the spectrum had been found to possess the power of separating silver from some of its compounds, and Humphry was now anxious to observe the effect for himself.

Having brushed a paper over with a solution of *nitrate of silver* (lunar caustic), he placed a strip of it a little way beyond the violet extremity of the spectrum; another strip he deposited in the violet ray itself; a third was left in the blue ray; while in each of the other coloured portions a piece of the same paper was exposed, and the light admitted to them all at the same time.

It was then found that the nitrate of silver darkened the *most* rapidly at that part of the spectrum a little *beyond the violet extremity*—that the chemical effect was the greatest after this in the violet ray itself. Next, the blue ray possessed a greater decomposing power than the green; whilst in the yellow and red rays no such power was perceptible, for the solution of silver remained undarkened there.

"So, then," cried Humphry, "the wonderful sunbeams that stream every day upon the earth contain not only all the colours of the rainbow, but three distinct, subtle principles, locked up in them —heat, light, and chemical influence; each of these being differently refrangible and existing in a ray of a different colour; the heat inhering in the red or lower portion of the spectrum, and the chemical power in the violet or opposite extremity, whilst the light occupies, as it were, a middle place, residing principally in the yellow portion."

Humphry then delighted his sister by preparing different chemical solutions, to be acted upon by the violet rays of the sun."

First, he made some *chloride of silver* by steeping a paper in salt and water and then brushing it over with a solution of *lunar caustic.* This he found to darken even more rapidly than the nitrate of silver itself, and he then set to work to ascertain the cause.

Now *chloride of silver* he knew to consist of chlorine (a green coloured gas) and silver, and he was anxious to see whether light would act upon chlorine more powerfully than it did upon nitric acid, as Mr. Wedgwood had told him.

Accordingly he filled a jar with equal portions of hydrogen and chlorine gases, and submitted this to the action of the sun's rays, when, to the astonishment of himself and terror of Kitty, the jar was no sooner placed in the sunshine than the two gases detonated with the noise of the report of a pistol, and the jar itself was almost shivered to pieces in the explosion.

Delighted with the result, and anxious to repeat the experiment in a less dangerous form, he filled a tube, about half an inch in diameter and twelve inches long, with the same gases, and while the end of the tube was inserted in a vessel of water, the upper part of it was shaded with an opaque cover, so that by removing this for an instant he could allow the gases within the tube to be acted upon by the light for as short a time as he pleased.

In this manner the ingenious youth found, that the moment the opaque cover was removed and the tube exposed, even to the diffused light of day, a cloudiness appeared within it, owing to the instantaneous, though silent, combination of the two gases, while the water rose more or less rapidly within it according to the intensity of the light. The effect even of a passing cloud was thus distinctly seen to retard the rapidity of the combination, while, when exposed to the full solar light, the union of the two was so instantaneous that the gases suddenly disappeared from the tube, and the water rushed violently up into it to fill the vacuum.

Next Humphry found that the two gases, when exposed to the sun's rays in a tube of violet-coloured glass, combine rapidly, but, strange to say, without explosion; whereas when they are submitted to the action of sun-light in a tube of red glass, the gases scarcely act upon one another. It was, moreover, ascertained, that when standing in a perfectly dark place, the two gases do not enter into combination in any length of time.

The lad could now understand why the chloride of silver darkened so rapidly in the sun's rays. The chlorine with which the metal was combined was attacked by the moisture in the atmosphere, and as this moisture consisted of oxygen and hydrogen in the form of water, the hydrogen of it was made by the chemical influence of the sunbeam to enter into rapid combination with the chlorine, and thus the silver was left behind, but in such minute particles that the metal, instead of appearing white as it usually does, assumed the form of a black powder, which, being fixed in the paper, naturally caused it to darken in those parts where the light had fallen upon it.

Filled with the knowledge he had thus obtained, Humphry set to work to produce some sun-pictures for his sister. Patterns of pieces of lace were thus made to impress their forms in a few seconds upon paper that had been prepared over-night with a coating of chloride of silver. Where the light fell, the silver was separated from the chlorine, and precipitated in minute black particles, so that the paper was darkened in those parts; while in the places where the threads of the lace prevented the rays from reaching the paper, the solution was undecomposed, so that a white line exactly corresponding to the pattern of the lace itself became impressed upon the black ground.

Kitty was overjoyed at the first picture she beheld her brother produce by the light, and Humphry smiled as he saw her take it to the window to examine it more minutely, for he knew that as she looked at it the light would begin to act upon the parts that had been previously screened by the lace itself, and where the solution still remained undecomposed in the paper; and sure enough, in a few minutes, she gradually saw the pattern vanish, and the whole ultimately become of one uniform dark-brown tint.

"What a pity," cried the girl, "that so beautiful a thing should be so perishable! If you could only find out, Humphry, how to fix the pictures, what a great thing it would be for you to do!"

The brother told her, that in order to accomplish this it was necessary to discover some substance that would remove the undecomposed chloride of silver, forming the white parts of the picture, and which would not attack the decomposed silver itself, forming the dark parts of it.

To attain this end, the young chemist made an infinity of experiments, but without avail; for though he tried a number of acids and alkaline solutions, he could find no liquid that would remove the undecomposed chloride from the paper, and after weeks of toil and disappointment he was obliged to confess, unwillingly, that the difficulty was one he lacked the power to master.

Many years after Davy's time, however, it was discovered that the chemical substance termed *hyposulphite of soda* readily dissolves chloride of silver, and has little or no action upon the precipitated silver itself; and from this period may be dated the perfection of the wonderful art of photography (or sun-painting) that Thomas Wedgwood was the first to attempt, and at which Davy himself was one of the early but unsuccessful experimenters.

Of this art there are now two distinct branches, viz. one in which the pictures are produced upon metal, the other upon paper or glass. In the metallic process, *iodide of silver* is the chemical agent rather than the *chloride;* this is formed by submitting a perfectly clean plate of polished silver to the action of the vapour of iodine, and sometimes to *bromine* afterwards, in order to quicken the action. The plate thus prepared is placed in the camera, so that an image of the object to be copied may fall upon it; the consequence is, that in the "*lights*" of the picture the *iodide of silver* becomes decomposed, the iodine itself going off in the form of *hydriodic acid* gas, by combining with hydrogen in the moisture of the air, and the pure silver being left behind; whereas in the shades of the picture where no light reaches, the iodide of silver remains undecomposed. The action usually takes place in some few seconds, according to the intensity of the light and the nature of the "quick" used. When the plate is removed from the camera no picture is visible upon its surface, so that the *developing* part of the process has then to be performed. This consists in submitting the plate to the fumes of mercury, which attach themselves to the parts where the pure silver has been separated from the iodine with which it was combined. These parts constitute, as we said before, the "lights" of the picture, and there the mercurial vapour is condensed, and clings in the form of minute globules; whilst to the parts which have been undecomposed the mercury does not attach itself, having no affinity whatever with the *iodide of silver* that remains there.

The consequence is, the globules of mercury which cling to the portions where the rays have fallen, reflect so much light to the eye that they form the "whites" of the picture; whereas the undecomposed iodide of silver, sending no light to the retina, constitutes the "blacks:" and thus the image, which was latent on the plate, is developed, or brought out, with such marvellous fidelity, that when examined with a microscope, characters that were several miles distant in the original may be clearly read in the minute sun-copy.

After this comes the fixing process, and that consists merely in submitting the plate to the action of *hyposulphite of soda*, which dissolves, and so removes all the undecomposed *iodide* of silver from it, and thus renders it incapable of being further acted upon by the light.

The above constitutes what is now usually known as the "*Daguerreotype* process."

The production of photographic pictures upon paper, on the other hand, forms what is termed the "*Talbotype* process"—the names of the two types being derived from those of their inventors. In the latter method of producing sun-pictures there are almost the same different stages to be gone through. The paper itself has first to be iodised, or rendered *sensitive* to the action of light, by means of coating it with a surface of iodide of silver. This is done by washing it over first with a solution of *nitrate* of silver, and when this is dry, with a solution of *iodide of potassium;* the consequence is, the one solution decomposes the other, so that nitrate of potash and iodide of silver are formed. The nitrate of potash, being soluble, is then washed out of the paper, while the insoluble iodide of silver remains fixed in it. Then follows the "*quickening*" part of the process. This consists in washing the sheet of iodised paper over with a solution of what is termed *gallo-nitrate* of silver, which consists of a small proportion of gallic acid (the acid from gall-nuts) dissolved in water, and added to a solution of lunar caustic, having a little acetic acid, or pure vinegar, in it. The gallic and acetic acids are used because it is found that the presence of any vegetable or organic matter hastens the decomposition of nitrate of silver when exposed to light. The paper is now ready for the camera, and is so sensitive to the action of light that it is said to transcend the ordinary iodised paper in this respect more than a hundredfold, so that even a second or two of time is sufficient to impress a latent image upon it.

Then, as in the daguerreotype method, the *developing* process has to be resorted to in order to bring out the picture, which is imperceptible on removing the paper from the camera, and the existence of which would not be suspected by any one who had not been forwarned of it by previous experiments. To render the picture visible, the paper is washed over once more with the gallo-nitrate of silver before described, and then warmed gently before the fire; whereupon that part of the paper upon which the light has acted begins to darken, while the other part of the paper retains its whiteness. After this, as in the "Daguerreotype" method, the *fixing* process has to be resorted to. This, for "Talbotypes," consists in washing the paper in *bromide of potassium*, which dissolves out all the undecomposed chemicals, and so leaves an indelible impression behind.

The picture thus produced, however, is what is termed a "negative" one—that is to say, the lights in the original are represented by shades in the photographic copy, and *vice versâ*, the shades in nature are rendered as lights in the picture. The Talbotype, therefore, has to be again copied, in order that the lights and shades may be accurately represented. For this purpose, however, the paper need not be so highly sensitive; so that the ordinary *quickening* part of the process by means of the gallo-nitrate may be dispensed with, or the paper may be coated with chloride of silver instead of the iodide before described. Again, the *developing* process is no longer necessary, the picture being produced *directly* by the action of light, rather than indirectly by means of some developing agent. The *fixing* process in this stage is usually performed by means of hyposulphite of soda, and by these means the negative picture before produced is rendered positive, and the lights and shades thus made an accurate representation of those in nature.

It will now be seen that the art of producing sun-pictures, whether by the Daguerreotype or the Talbotype, comprises usually four distinct processes, viz.:

1. The *preparatory* process, which consists in preparing the plate or paper—that is to say, in coating it with some solution of silver that is capable of being decomposed by the action of light.

2. The *quickening* process, which consists, again, in rendering the plate or paper more highly sensitive to light by the addition of some other chemical, which facilitates the decomposition of the compound of silver, with which the surface has been previously coated.

3. The *developing* process, which consists in rendering visible the latent picture which has been impressed upon the plate or paper while exposed to the action of the light in the camera.

4. The *fixing* process, or the dissolving out of all the undecomposed silver compound, and so preventing the light from having any further action upon it.

Now it must not be supposed that the compounds of silver are those only which are capable of being decomposed by the sun's rays, for photographic pictures have been produced by compounds of all the precious metals—such as gold, platinum, mercury, &c., these substances having but slight affinities, and so being easily separable from the elements with which they are united. Again, iron has been used successfully for the same purpose—for this body, also, is readily decomposed when combined with certain substances. Further, the gum-resins and bitumens admit of being employed in the same manner, and many vegetable juices have been used by Sir John Herschel for a like purpose. Indeed it has been truly said, that almost every substance in nature is affected, in some way or other, by the solar rays, for we now know that no substance can be exposed to the sun's rays without undergoing chemical action.

The changes, therefore, that are continually occurring in the external world are quickened by the rays, which at one time it was believed gave only light and heat to the globe that we inhabit; and even the very changes of the seasons, the growth of vegetation, the blossoming of the flowers, and the ripening of the fruits, are all due, in a measure, to the chemical influence of those elementary rays which lie concealed in the compound sunbeam: for it has been proved that the sunshine itself is necessary, even to the breathing of plants through their leaves, and that in the shade they cease absorbing the carbon from the atmosphere which is ultimately destined to form part of their woody structure. Thus light becomes not only the source of beauty to the world, and the agent upon which one of our most wondrous senses depends, namely, that by which we are enabled to recognise the form and nature of objects at a distance from us, but it is also the source of health and vigour to our frames, by maturing the products of the earth upon which we live, as well as by promoting in our own frames those subtle chemical changes, by which our bodies are nourished and our faculties developed, since in darkness men can no more thrive than plants.

Had Davy lived to see the development of the chemical influence of light that has been opened up to us since his time, he would have been the loudest in his praises of the marvels wrought by it, and, doubtless, among the foremost to have extended our knowledge of its action. But these are discoveries made since his time, and discoveries which he, with his deep insight into Nature, was unable to foresee, or even to assist. To such perfection, however, has the photographic art been carried since the days when Davy vainly essayed to fix the images which took him some quarter of an hour to produce, that not only can stationary objects have their forms indelibly impressed upon paper by the very light itself which renders those forms visible to us, but the passing shadows that give beauty to the landscape can be made permanent, the very undulation of the corn can be seized, the rustling of the leaves detained, and even the rippling of the waters, the playing of the fountains, and the curling of the smoke, whose particles never for two moments together remain in the same place, can be arrested, and their evanescent forms painted by themselves, as it were, upon the tablets; so that the effect of a mere instant can, by its marvellous agency, be prolonged for years. Thus time, which is known to us only by the changes which are continually occurring without and within us, has all the fixity of space; and those historical events which our forefathers were unable to convey to us, from the want of some such art, can now be handed down, rendered with all the truth of light itself, so that future generations gazing at them may behold the same scenes that were impressed at the back of our eyes years before. Indeed, the photographic art itself is but the process of individual and transient vision made universal and permanent; for the eye itself is but the camera through which we gaze at the world without, and the retina at the back of the organ of sight no more than a photographic plate, as it were, impressing the images that flit before our vision more or less permanently upon our memories.

As an instance, however, of the perfection, we repeat, to which this process of fixing the most transient images has been carried, we need only mention the experiment performed by Mr. Talbot, in which a moving body, that was made to revolve at an enormous speed, and that was illuminated but for an *instant* by the electric spark, was photographed as a stationary object.

It is well known that a wheel revolving at a rapid rate is barely visible to us, the spokes passing with such velocity before the eye that we are unable to distinguish one from the other, so that the whole appears to us almost as one entire disc; such a wheel, however, if made to rotate in the dark, and then suddenly illuminated for that inappreciable portion of time which the electric spark—the miniature lightning of the laboratory—endures, then appears to us as if absolutely standing still; for as we see it under such circumstances only in that place which it occupies so long as the light lasts, and this being but for the least conceivable term of duration, it has no time—however rapidly it may be turning on its axis—to pass from one point of space to another, so that it can but appear to us as if utterly stationary.

In the experiment we allude to, a wheel was thus made to revolve so rapidly, that its revolutions were counted by the musical note produced by the vibrations of a spring, that moved backwards and forwards once at each turn. The revolutions were performed in the dark; and during this the chamber and wheel were suddenly lighted by one spark drawn from a powerful electric machine. At this moment a photographic apparatus was presented to the wheel itself, and on developing the image thus produced upon the paper which had been previously inserted in the camera, it was found to be impressed with a perfect copy of the wheel itself, with all its spokes distinctly visible, and precisely the same as if the image had been taken from the wheel while in a state of rest. It was the same stationary image, too, as the spectators themselves had beheld during the instantaneous illumination of the object; and thus, by the aid of the same fluid as the lightning itself, and with the assistance of music to register the rate of revolution, that mysterious principle of motion which has puzzled philosophers since philosophy began, was made to appear like rest, and even the sensibility of the eye itself rivalled by photographic agency, so that the dead paper was made to be impressed with the very same figure as the living retina itself perceived.

CHAPTER XVIII.

CONCLUSION.

During the prosecution of his later experiments Humphry had formed the acquaintance of Mr. Davies Giddy, a gentleman of high scientific attainments, better known under the name of Davies Gilbert, and who was then resident at Tredrea, near Penzance.

This gentleman, who ultimately became President of the Royal Society, proved of great service to young Davy, for not only did he lend the boy such apparatus as he required for the carrying out of his experiments, but he delighted to converse with Humphry; and though he could not help smiling occasionally at the strangeness of his theories, he grew to have a lively sense of the ardour of the youth's imagination, and the originality of his mind.

Now it so happened that Davies Giddy was acquainted with Dr. Beddoes, who had formerly been one of the Oxford Professors, but who had recently opened a Pneumatic Institution at Bristol for the cure of diseases by the inhalation of gases; and it was during one of Dr. Beddoes' visits to Davies Giddy that Humphry made the acquaintance of the Doctor, and so favourable an impression did he make upon the gentleman, that not long afterwards a letter was sent, offering Humphry the post of Assistant to the Bristol Institution.

The lad was delighted at the prospect of removing from so remote a place as his native town, and lost no time in talking the matter over with his friends. Mr. Giddy told him of the Doctor's influence, and how his Institution was already the resort of some of the most eminent persons in the country, and warmly advised him to avail himself of the offer.

Mr. Borlase, to whom Humphry repeated all that Mr. Giddy had said, counselled the boy to take the same step, and added, that he had been so pleased with his conduct while under his roof that he would in no way impede his advancement, but would rather cancel his indentures, even though he was just beginning to be of service to him.

Mrs. Davy, too, was anxious that her boy—whom she felt more and more convinced was destined to take a high rank in the world—should be transferred to a wider sphere, where his abilities would have greater chance of being called into play, and she gladly accompanied Humphry to their old friend, Mr. Tonkin, to break the matter to him, and hear what he thought of the proposal.

The old gentleman, however, could not be made to listen to the project, and did not hesitate to denounce Humphry's desire for worldly honour as the "wild-goose chase" which led many an ambitious simpleton astray, saying, that if the boy would make up his mind to settle in his native place, he might be assured of a comfortable independence, for he would find but few able to compete with him there. Nevertheless, in a large town—however striking his talents might appear in a small one—the circle of his competitors would be so much increased, that he would sink into a mere nobody, and end his days as one of the many fools who had struggled after the world's prizes, and found, when too late, that there was no chance of obtaining them.

Mrs. Davy, however, mother-like, felt satisfied that Mr. Tonkin took an erroneous view of her son's powers, and she strove to assure her old friend that he did not know what Humphry was capable of doing so well as she did, and that if he did, he would have as little fear as herself of his failure.

Mr. Tonkin, however, was not to be argued out of the notion he had taken up, and ultimately grew so annoyed with what he fancied to be merely a mother's silly prejudice on Mrs. Davy's part, that he ended the interview by vowing that the boy should never quit Penzance with *his* consent.

This, for a time, put a stop to the correspondence on the subject. At length, however, Dr. Beddoes became so urgent that Humphry should join him, that, despite the objections of Mr. Tonkin, who still would not listen to the plan, his friends advised him to accept the offer; and it was accordingly arranged that young Davy should leave Penzance as soon as he conveniently could.

Accordingly, on the 2d of October, in the year 1798, Humphry, not then twenty years of age, quitted his native town for the first time in his life, and that to commence fighting his way in the world.

His mother parted from him as full of high hope as the boy himself; and as the boy hugged the widow to his heart alone in her chamber, before he left her, he said, with the sobs in his throat, "Mr. Tonkin does not know me, mother, yet: but be you of good cheer, I will live to be an honour and a glory to you still; and it shall be my proud lot to say some day that I was the means of raising you and all that belong to me to a position of comfort and eminence. Years ago now, mother, I told you I *would* do it, and the resolve is still *deep* in my heart."

Mrs. Davy assured him she had every confidence in his attaining the noble object he had in view, and she parted from him, though with tears in her eyes, with a smile of high hope upon her lip.

Mr. Tonkin, however, was resolute to the last, and at his leave-taking denounced Humphry's plans as visionary schemes; and when the boy had left, and the old gentleman found his favourite plan of settling Humphry in his native town as a surgeon had been thwarted, he altered his will, and revoked the legacy of the house that he had previously bequeathed to his foster-son.

On young Humphry's journey to Bath he met his friend Mr. Davies Giddy at Oakhampton, and while breakfasting there, the mail-coach from London drew up at the door of the inn, covered with laurels and ribbons, and bringing the first news of Nelson's victory of the Nile.

"I have a greater fight than that to fight," said Humphry to himself; "and, please God, I will gain the victory, too."

It was Mrs. Davy's happy lot to witness the realisation of all the hopes she had formed of her boy in his youth; for, during her life, he rose to be elected President of the Royal Society, and to be created a Baronet, for the many additions he had made to the stock of knowledge; to be rewarded with the first prize instituted by the Emperor Napoleon for the greatest scientific discovery of the time; and to be allowed a free passage through France at a time when all other Englishmen, no matter how high their rank or character, were denied admission into that country.

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THE END.