THE WONDER BOOK OF LIGHT

EDWIN J. HOUSTON

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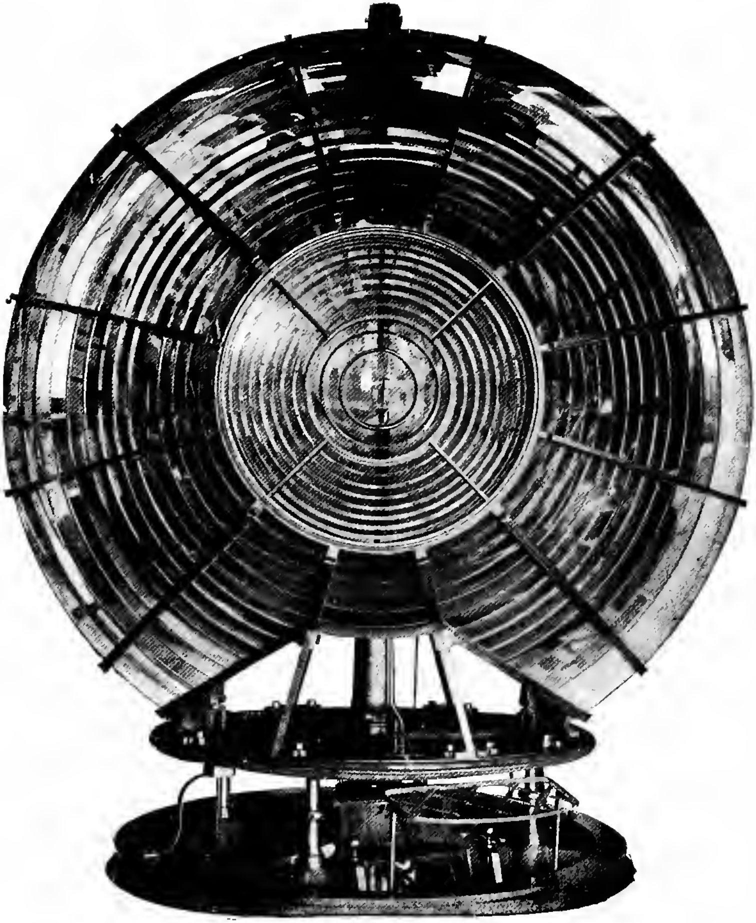


LARGE LIGHT-HOUSE LENS

Exhibited at the Chicago World's Fair, in 1893, and was employed in connection with a nine thousand candle power arc light.

By courtesy of "The Scientific American"

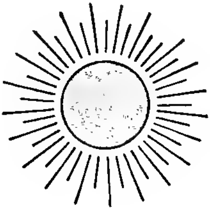
THE WONDER BOOK OF LIGHT

BY

EDWIN J. HOUSTON, Ph.D.

Author of "The Wonder Book of Volcanoes and Earthquakes," "The Wonder Book of the Atmosphere," "The Wonder Book of Magnetism," etc.

WITH 115 ILLUSTRATIONS



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Dedicated to my Friend

L. WEBSTER FOX, M.D., LL.D.,

Professor of Ophthalmology in the Medico-
Chirurgical College of Philadelphia,
in appreciation of the encouragement given me in
the new field of juvenile literature

PREFACE

Light, though one of the most difficult of all the natural forces to explain thoroughly, contains within it so many wonders that it can be made attractive to young and old alike.

The author has not hesitated, in either this or the other Wonder Books, to employ freely a few of the old, old fairy stories for illustrating some especially difficult point. It is his experience in the teaching of the natural sciences to the young, that the more unusual or out-of-the-way the illustrations employed, the greater the chance of their producing a marked effect on the mind.

At the same time, however, too elementary a treatment has been carefully avoided. Especial care has been taken to employ the optical terms in general use; for there is no more difficulty in learning the correct scientific names than in remembering a number of *fictitious* names. In this way the reader has laid up in his or her memory, along with the elementary principles of the science of optics, information that cannot fail to be of great value in after years.

The author acknowledges his indebtedness to his friend, Dr. L. Webster Fox, Professor of Ophthalmology in the Medico-Chirurgical College of Philadelphia, for reading the proof sheets.

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E. J. H.

Philadelphia, 1908.

CONTENTS

CONTENTS

ILLUSTRATIONS

FULL-PAGE

ILLUSTRATIONS IN THE TEXT

ILLUSTRATIONS

ILLUSTRATIONS

ILLUSTRATIONS

THE WONDER BOOK OF LIGHT

The Wonder Book of Light

CHAPTER I

INTRODUCTORY

In his inspired account of the creation of the world, Moses begins with the statement that when, in the beginning, God created the heaven and the earth, the earth was without form and void and darkness was upon the face of the deep. The creative spirit of God moved upon the face of the waters: "And God said, Let there be light; and there was light. And God saw the light that it was good." Then the light was divided from the darkness, and the light called day and the darkness night. The first great act in the creation of the world was completed. For the first time night, following day, falls on the earth.

During the second day, or the second great creative period of time, as the word day is now generally understood, God made the firmament, and divided the waters that were under the firmament from those that were above. Night again falls on the earth, and the second day's work of creation is completed.

On the third day, at the divine command, the waters under the heaven are gathered together into one place and the dry land appears, and the earth brings forth grass, the herb yielding seed after his kind, and the fruit tree yielding fruit after his kind, whose seed is in itself, and darkness again falls on the face of the earth, and the third day's work is completed.

Had it not been for the creation of light on the first day, God's great gift of the herb yielding seed and the fruit tree yielding fruit would have been futile; for it was only under the awakening influence of light that the seeds germinated. It is only because of the action of light that plants can take from the carbonic acid of the atmosphere the food they need for the formation of their woody fibre.

The fourth great creative period or day now dawns on the earth. At the divine command, lights appear in the firmament of the heaven to divide the day from the night, the sun to rule the day, the moon to rule the night; and night again falls on the earth.

We must not forget that in the account Moses gives of the creation of the world, he is telling how things looked to him as God caused a vision of the creation to pass, as it were, in panoramic view before him. We know that the sun and the stars were created long before the earth, but by reason of great clouds of steam and vapor, their light was completely hidden from the observer. They are, therefore, spoken of as being brought into existence only so far as the earth itself is concerned.

On the fifth day came the great creation of marine life. The waters brought forth abundantly moving creatures that have life; fowls that fly in the air above the earth, and great whales, and every living creature that moves in the water. Night again falls on the earth and another great creative day has passed.

On the sixth day comes the creation of the land animals, cattle and creeping things, and beasts of the earth, and then followed the greatest of all creative acts, when

God made man in his own image and breathed into his nostrils the breath of life.

I do not think I could begin The Wonder Book of Light in any better manner than by thus describing briefly to you the wonderful account that Moses gives in the Bible of the creation of the world. When properly read and understood, I feel, as a man who has given considerable attention to the manner in which the earth has been gradually developed or created by God, that this account is wonderful in its general accuracy as to the order in which the different creative stages followed one another. Considering the early date at which Moses wrote it would clearly have been impossible for him to have obtained such knowledge as is found in his account in any other way than as an inspiration from God.

I hope by the time you have finished reading The Wonder Book of Light, and have thoroughly grasped the different matters that will be brought to your attention, you will be better able to appreciate how very, very good was the light that God called into existence at the beginning of earth's first creative day.

It is customary, in undertaking the description of any natural phenomenon, to define the meaning generally given it. This, we must agree, is an excellent method. You will probably wish to ask me the question: "What is light?"

Now it happens this was the question that Sir Oliver Lodge, one of the most celebrated and ablest of English philosophers, put to himself while delivering a popular lecture at the London Institution, December 15, 1880, on the relations existing between electricity and light.

When Lodge put to himself the question, "What is electricity?" he very properly answered, "Nobody knows." At the same time, however, he suggested that the inability to answer this question need discourage no one, since in a certain sense we do not know any more about either matter or energy.

When Lodge came to answer the second question, "What is light?" he gave the following answer—I quote it here in his own words, for to my mind it is expressed in charming language:

"Now we will pass to the second question; What do you mean by light? And the first and obvious answer is, everybody knows. And everybody that is not blind does know to a certain extent. We have a special sense organ for appreciating light, whereas we have none for electricity. Nevertheless, we must admit that we really know very little about the intimate nature of light—very little more than about electricity. But we do know this, that light is a form of energy; and, moreover, that it is energy rapidly alternating between the static and the kinetic forms—that it is, in fact, a special kind of energy of vibration. We are absolutely certain that light is a periodic disturbance in some medium, periodic both in space and time; that is to say, the same appearances regularly recur at certain equal intervals of distance at the same time, and also present themselves at equal intervals of time at the same place; that in fact it belongs to the class of motions called by mathematicians undulatory or wave motions."

When, therefore, you ask *me* what is light, I can answer with Lodge that you all know what light is. You know it by its many effects. It is the great agency that not only drives away the darkness which covers the face of the earth during night, but that also lights up surrounding objects and enables us to distinguish readily their colours, forms, and appearances. It is the potent form of energy that awakens the vegetable germs in the earth, so that the grass may grow, the herb may yield its seed and the fruit tree may yield its fruit after its kind. Moreover, after these have been started into life, it is the power by means of which they are supplied with food from the atmosphere for the production of their woody tissues, through the decomposition of the carbonic acid gas the plants breathe in from the air.

It is a wonderful thought, that the delicate structure of the leaf of the living plant is not only able to act as the lungs, by which it can take in carbonic gas from the air, but also as the laboratory in which, under the decomposing power of light, the combination between the oxygen and the carbon is broken up, the oxygen thrown out into the air, and its carbon retained for the formation of its woody tissues.

Should light disappear entirely and forever, our beautiful earth would soon become a vast charnel house. Darkness would then again brood over the face of the deep, and silence and death would reign supreme.

You will recall the fact that when God created male and female, he blessed them, commanding them among other things to subdue the earth; that is, to have power over the natural forces he had created.

I sometimes think that one of the most important directions in which man has subdued the earth is in his ability to produce light artificially, so as to be able to extend the day far into the night. Man is no longer obliged, as were his ancestors, to cease from his labor and seek rest in sleep, on the setting of the sun, when, in the absence of moonlight, there is no light by which he can work.

Man's first invention for turning night to day, was crude indeed—a mere burning fagot, snatched hurriedly from the fire. It was but a poor means of illumination, yet it permitted him to go some little distance from his dwelling, and, to a certain extent, to prolong the time during which he could work.

The next improvement was the invention of the rush light, practically the candle. Then followed the invention of the oil lamp. These were great inventions, although, when compared with the more complete devices of to-day, they seem poor and crude.

Then, after a long while, the invention was made that introduced illuminating gas into our houses, and the gas burner took its place as one of the marvels of that time. In its turn the gas light was to a great extent displaced by the arc and incandescent electric lamps. At a somewhat later date, there was such a marked improvement either by the invention of the Welsbach incandescent mantles, or by the replacing of ordinary illuminating gas by acetylene gas, that the use of gas for illumination greatly increased. These, and other improvements, have left the world in a wonderfully advanced condition, so that man is now able to prolong the day by extending it far into the night.

While the inventions which have been made for the production of artificial light, may properly be regarded as among the most noted of man's achievements, yet I am not quite sure that they have produced results entirely devoid of evil consequences. One of the conditions nature has imposed on man, in order that he shall retain his health, is that he shall rest or sleep during a certain number of hours each day. If he foolishly fail to take this rest he must, sooner or later, pay a dear price for his disregard of nature's laws. I would, by no means, advocate the re-establishment of the curfew bell, on the ringing of which, as you know, all lights were to be extinguished and everyone was to go to bed. The world has gone too far for that; the curfew is a thing of the past. Night work is now essential. Take the case of any large city, such as London, New York, or Philadelphia. It is during the small hours of night, while most people are asleep, that the bread is made and baked, the food products prepared and brought into the city, and the great newspapers printed, so that they can be placed on the table the next morning, at the meal which marks the break of man's long fast. Should artificial illumination be no longer employed, the world would be set back in its civilisation to an extent that would seem almost incredible.

The immensity of this night work was thoroughly appreciated during the siege of Paris by the Germans, when the government had to provide for the feeding of the inhabitants. The same thing has doubtless been experienced during other sieges which to a great extent have shut cities off from the outside world.

CHAPTER II

PROPERTIES OF LIGHT

WHILE I believe that most of the interest attached to those fairy stories which have been handed down from generation to generation, arises from the apparent improbability of their fulfilment in actual life, yet what gives them an added charm, to the more mature mind, is the thought that in nearly all these stories there are suggestions of some great truth in physical science. Indeed, I feel that it is due to this fact that I am as fond now of fairy stories as I was in my childhood.

Perhaps some older readers may feel disposed to look on the use of fairy stories in books like The Wonder Books, as bad taste, or out of place. They are well enough, they may say, in nursery stories, but have no proper place in books of this character. Now I want to say here that I do not at all agree with this statement. Science is so full of the most wonderful fairy stories that I may, some of these days, write an entirely new series of these stories, in which I will describe the wonderful forces of the physical world in the guise of fairies. It will suffice here, however, to say that, even if no other advantage were gained by their use in The Wonder Books than that of directing the attention of young readers to the strange manner in which some important fact in nature has been explained, their use would be more than justified. Although fairy stories are literally untrue, yet they cannot fail to impress on our minds any great principle in science they have been employed to illustrate.

And now, as we come to a matter in light that is hard to understand, and is, moreover, generally stated in a dry and uninteresting manner, I am reminded of the beautiful story of Graciosa and Percinet.

Like all fairy stories it begins with the phrase, " Once upon a time," as if it were endeavouring to establish its claim to belief on the pretense of limiting the occurrences described to a definite time. " Once upon a time " there was a King and Queen who had a daughter named Graciosa, a charming princess, worthy the name they had given her. The King, Queen and Princess lived happily together until the Queen died. Now, unfortunately, the King was a great lover of riches, and, still more unfortunately, there lived in his kingdom a rich Duchess so deformed and ugly, both in body, mind and disposition, that she was known among her neighbours as Grumbly, a name that suited her extremely well.

The Duchess was jealous of the Princess because the Princess possessed qualities or properties of which she was so deficient. Taking the first opportunity that presented itself, Grumbly, who was enormously wealthy, permitted the King to examine her treasures, and promised to give them all to him if he would only marry her. She made it a condition, however, that Graciosa should be placed entirely in her power.

Now, although the King dearly loved his daughter, yet he loved riches more. He, therefore, made a miserable bargain and sold himself to the Duchess for her wealth, thus not only cheating his daughter out of a father's love that was hers by right, but also cheating the Duchess, who received for her money so poor a specimen of a man that he did not begin to be worth the price she paid for him.

Great preparations were made for the marriage. The Princess had no difficulty in dressing so as to look exceedingly charming. With the Duchess, however, it was quite a different thing. However, she tried her best. By making the heels of one of her shoes half an inch higher than the other, she somewhat decreased her limping gait. By padding her clothes, she hid some of the crookedness of her body. An artificial glass eye, made to replace one she had lost, caused her face to look somewhat less ugly. Then she dyed her red hair black, put a blush on her yellow face by rouge, and hid her wrinkles under enamel. Indeed, when thus adorned, she might have been fairly good looking at a distance if she had not displayed such awful taste in dressing. But the colours of the materials she employed were so abominable in their contrast that there was probably never a more awful looking dress, despite the fact that it cost so much money.

There lived in the same kingdom an extremely agreeable and beautiful young prince named Percinet, who possessed immense wealth and at the same time had certain fairy gifts that made him very powerful. He had for a long time been in love with Graciosa. Hearing of the approaching marriage and knowing the danger that threatened Graciosa, he dressed himself as a page and went to her, offering his protection.

As soon as the Duchess saw the lovely Princess seated on a spirited horse that Percinet had brought her, and which he was leading as her page, she became jealous, and told the King that unless the Princess' horse was given to her, as well as the page who was leading it, she would not marry him. The King agreed to do as she demanded. Somehow or other, I think you and I can guess why, the horse ran off, the Duchess was dragged through the mud, and her clothing was torn. But the marriage went on, nevertheless, and Graciosa was delivered into the power of the Duchess, who was now her stepmother, the Queen.

Although unable actually to prove it, the Queen felt sure that her troubles had come from Graciosa. She, therefore, commanded her servants to carry her daughter-in-law to a great forest, one hundred leagues from the palace, and leave her there alone, believing that the wild beasts would soon devour her. Graciosa, however, was rescued by Percinet and taken to his palace, where she was welcomed by his mother. After a happy eight days, Graciosa persuaded Percinet, much to his regret, to take her back to her father. As soon as she entered the palace she was again placed in the power of her stepmother, the Queen, who determined to kill her. In order, however, to pretend that she did this only because of the Princess' disobedience, the Queen summoned some wicked fairies, and commanded them to set some impossible tasks for the Princess.

A number of tasks were set, none of which Graciosa was able to perform. In each case, however, at the last moment, Prince Percinet appeared, and by a mere touch of his magic wand, the task was instantly completed.

Furious that she has found nothing Graciosa was unable to perform, the Queen, after consulting with a wicked fairy, at last set her a task that certainly seemed to be impossible.

Now as this is a part of the story I intend to use, in order to illustrate a difficult point in light, a point that is all the more difficult because at first sight it seems easy, I will quote somewhat in full:

"The next day the Fairy appeared with a huge barrel full of the feathers of all sorts of birds. There were nightingales, canaries, gold finches, linnets, tomtits, parrots, owls, sparrows, doves, ostriches, bustards, peacocks, larks, partridges, and everything else that you can think of. These feathers were all mixed up in such confusion that the birds themselves could not have chosen out their own.

"'Here,' said the Fairy, 'is a task which it will take all your prisoner's skill and patience to accomplish. Tell her to pick out and lay in a separate heap the feathers of each bird. She would need to be a fairy to do it.'

"The Queen was more than delighted at the thought of the despair this task would cause the Princess. She sent for her, and, with the same threats as before, locked her up, ordering that all the feathers should be sorted by sunset. Graciosa set to work at once, but before she had taken out a dozen feathers she found that it was perfectly impossible to know one from another.

"'Ah! well,' she sighed, 'the Queen wishes to kill me, and if I must die I must. I cannot ask Percinet to help me again, for if he really loved me he would not wait till I called him, he would come without that.

"'I am here, my Graciosa,' cried Percinet, springing out of the barrel where he had been hiding. 'How can you still doubt that I love you with all my heart.'

"Then he gave a stroke of his wand upon the barrel, and all the feathers flew out in a cloud and settled down in little separate heaps all round the room.

"'What should I do without you, Percinet?' said Graciosa gratefully. But still she could not quite make up her mind to go with him and leave her father's kingdom forever; so she begged him to give her more time to think of it, and he had to go away disappointed once more."

I imagine I see some of you after looking at the first part of the chapter heading, inquire, "What possible connection can the remarkable fairy story just told have with such an unattractive and dry subject as 'The Properties of Light,' whatever that may be? Perhaps that word "properties" is perplexing you as I remember once it did me. Let me first tell you briefly its exact meaning, and I will then tell you what this fairy story has to do with this chapter.

Strictly speaking, a property is a belonging or a possession. If someone should make you a present of a fine four-story brick house, he would be giving you something that could be correctly spoken of as your property, and, if you had several houses, they could be spoken of as your properties.

Now the word property is employed in a somewhat similar sense in physical science. But here it means more than this. A property is not only a belonging; it is a belonging, sufficiently different from the belongings of other things, to enable one readily to recognise this particular thing. It is in this sense that we have used the words "properties of light."

By the properties of light therefore, we mean those belongings or peculiarities that enable us to distinguish the peculiar force called light from other forces. Let me, therefore, tell you some of these properties of light, remembering all the time that you are to try to find one particular set of properties that will remind you of the barrel filled with feathers in the fairy story of Graciosa and Percinet, as well as the wonderful manner in which by a touch of his wand all these feathers instantly arranged themselves in separate lots. In order the better to do this, let me ask you carefully to examine a patch of bright sunlight, such, for example, as the patch that may fall on a sheet of white paper lying on the floor, or on the table.

There certainly seems to be nothing magical about a mere patch of sunlight. It seems to be only an uniformly white space, wonderfully bright, wonderfully steady, pleasantly warm in winter, and sometimes disagreeably warm in summer. You therefore say, and I am not surprised to hear you say it: "I see nothing here to remind me of any fairy story."

I can only say: wait a while. I don't expect you to understand this matter at first sight. It took many exceedingly bright men to observe, experiment and examine that patch of sunlight before *they* saw anything curious about it. Give me your close attention while I name some of its properties.

In the first place, that patch of sunlight does not consist of any kind of matter. It is a variety of force. It is not a material thing but a peculiar condition in which energy is capable of existing, and, indeed, in which any other form of energy can be readily made to show itself, if only one learns how to make it do so. In other words, no matter from what source it may have been derived, whether from a steam engine, from the force of the wind, from a falling body, from electricity, magnetism, heat, or from the elasticity of a bent-spring, energy can be changed into light; that is, can be made to produce light. Being a force, light, like all other forces, is weightless. Therefore, while you are looking at that patch of sunlight I wish you to bear this in mind; it possesses no weight. This property of light cannot remind you of the feathers because feathers *do* possess weight.

The next property or peculiarity of light is that it is by no means as still as it appears to be as it lies so quietly on that patch on the sheet of paper or on the floor. It possesses the power of moving from place to place in perfectly straight lines.

You can easily convince yourself of this as follows. Place a small piece of looking glass on a piece of paper, so that some of the light falls on it. As you well know, the light will be thrown off from the glass and will appear on the ceiling or somewhere else. You can still see, on the part of the paper not covered by the glass, the light that is coming from the sun. You can also see it on the ceiling. If you wish to follow the path of the light, raise a smoke in the air by burning paper. The path of the light can then be easily seen.

Some of the light, thrown off in all directions from the smoke particles, enters your eyes, and enables you to see the line of particles that have been lighted up in the direction of its path.

There is another way in which it can be proved that light moves or travels in straight lines. Objects become visible by means of the light they throw off in all directions. Now carefully looking at any object, hold a sheet of paper, a book, or any opaque body, between your eyes and these objects, and slowly raising it higher and higher, notice how the objects instantly disappear as the opaque body comes between them. Notice, moreover, that the portions of the objects that are thus removed from view will take the outlines of the edges of the book or other object. This is because the rays of light, coming in straight lines from the objects, fall on the book, and, being unable to pass through it, fail to enter your eyes. If you use a circular or triangular piece of paper, the portions of the objects cut out from view will possess the outlines of the paper. The same is true if holes of any shape be cut in the paper, for the outlines of portions of the objects seen will be strictly those of the holes.

There is still another proof that light travels in a straight line. When a man wishes to shoot a bird, with a ball from a gun, he is safe in assuming that the light by which he sees the bird passes between it and his eye in a perfectly straight line; for, aiming his gun straight in this direction, allowing, of course, a trifle for the fall of the ball while passing from the gun to the bird, if his aim is correct, and his gun shoots true, the ball will undoubtedly strike the bird.

The facts that sunlight can move and that it moves in straight lines are two other properties of light. But neither of these can possibly remind you of the big barrel crammed full of all kinds of birds' feathers.

Another property of light is that it moves rapidly from place to place. Indeed, this motion is so swift that you cannot detect it. Light travels much more rapidly than sound. If you are standing where you can see a distant man strike a blow with a sledge hammer, you can see the hammer strike long before you can hear the sound. As you know, the sound instantly follows the blow, but if the man is say half a mile distant, quite a little time will pass from the time you see the hammer strike before the sound reaches you. This is because the light travels so much more rapidly than sound.

If you wish to convince yourself of this, take a piece of looking glass off the table, and see how many you can count while holding it in different positions in the sunlight before the light flying off the mirror strikes the ceiling or a distant wall of a room. If you try this you may come to the conclusion that it does not take any time to pass through this distance. It's there before you see it. I answer of course it is; for if it were not there you would not be able to see it. But to get there it must have passed from the mirror to that part of the wall, and to enable you to see it, it must have come from that part of the wall to tell you that it was there, so that it must have passed twice through this distance.

You would have the same trouble, if, taking the looking glass to the window, you permitted the patch of light to move across the street to one of the opposite houses, or even to a considerable distance up and down the street. The light moves so rapidly from the mirror that it seems to you to take no time to move from place to place, or, in other words, its motion seems to be instantaneous. But you must not get the idea that light requires no time to travel from place to place. It does require time, although this time is exceedingly small; for, as we shall show in a subsequent chapter, the speed with which light moves, or its velocity, is so great that it far exceeds the speed of the swiftest locomotive. Indeed, the best locomotive moves at but a snail's pace when compared to the motion of light; for, while the locomotive can move at say about 90 miles an hour, light can travel with a speed greater, in round numbers, than 186,000 miles per second or 669,600,000 miles per hour.

Now this enormous speed is another property of light. But it can certainly in no manner suggest to you the big barrel of birds' feathers.

But there is still another peculiarity of light that you certainly would never be able to detect by merely watching the patch of sunlight on the sheet of paper. Light does not consist of a single thing. It consists of a great number of different things; or, as will be shown in another chapter, of waves set up in an imponderable medium, called the ether, that exists not only throughout all portions of space but even in between the small particles of which matter is composed.

Like sound, light is the result of a wave motion, and that patch of sunlight you are looking at on the piece of white paper consists of an enormous number of waves of different lengths.

Perhaps you will be able to form a clearer idea of this fact if we take the somewhat simpler idea of a musical sound. Suppose a sound is produced by striking all the strings of a piano, at the same time. Now while a trained ear can distinguish the separate notes that are thus sounded, yet to most ears they seem to consist of a single noisy tone only.

That patch of sunlight which lights up the sheet of paper is more complex and contains a greater number of separate kinds of light waves than would the sound produced not only by striking at the same time all the strings of a single piano, but even all the strings of many pianos differently tuned.

But the patch of sunlight is even more complex than this. Besides the light waves it is giving off, which are able to produce different effects on the eye, there are other ether waves far greater in number than even the visible waves that are unable to produce any effect on the eyes. These are the waves called heat waves, or, as they are sometimes called, waves of 'dark light.' They are much longer than the light waves. Besides these there are still other sets of waves, shorter than light waves, that are too small to affect the eye, but produce curious effects in matter called actinic effects. In other words, the white patch of sunlight is extremely complex, consisting as it does of many kinds of waves that can affect the eye as light; and of a still greater number of heat waves that are too long to affect the eye, as well as a great number of waves that can produce photographic effects, but are far too short to influence the eye. Moreover, these invisible waves are very much greater in number than the visible waves.

I am sure all of you can now see that in this last property of light—its wonderful complexity—is to be found the suggestion of the fairy story of Graciosa and Percinet. In that patch of light, which seems so simple as it shines on the sheet of paper, there are far more kinds of light waves than there were feathers that the wicked Queen had set for poor Graciosa to sort out before sunset.

Possibly some of you may say, "Are you not stretching a point here? Is it possible that in so common a thing as sunlight any proper comparison can exist between the different kinds of waves and the actual number of differently coloured feathers that were crammed in that great barrel?"

I am glad you asked this question. I can assure you I have not forgotten what you have suggested, and when we come to study light more carefully, I am sure you will agree with me that, if there is any absurdity whatever in the comparison, it lies in comparing a barrel filled with the feathers with the sunlight itself. It will, of course, take some little time for you to get an adequate idea of the complexity of sunlight. I will merely tell you now that in the part of the spectrum capable of affecting the eye, there are no less than 2,000,000 different kinds of waves, and that, besides these, there is a still greater number of wave lengths that are unable to affect the eye.

I will not, however, keep you in suspense until we have gone so far through The Wonder Book, but will simply say that, if you can get one of the prisms from a glass chandelier, or from some other place, you will have in your possession the magic wand of Prince Percinet by means of which in that very short space of time that is called by the Germans "ein Augenblick" or "a wink of the eye," you can make the separation yourself. For, if you now examine that patch of white light, through the prism, you will be able to see its separate constituents as wonderful groups of coloured lights of almost innumerable tints of reds, oranges, yellows, blues, greens, violets, and indigoes.

If, therefore, you were in the place of poor Graciosa and heard the wicked Queen coming to have you killed because your task had not been completed, it would not be too late even if you heard her footsteps coming up the stairs. It would not be too late even if you heard the key turning in the door lock, for you need only permit the light to pass through the prism and in less than the twinkling of an eye, all the many feathers—that is, all the different coloured light waves—will have been sorted out in separate patches that will have collected on the floor before the door opens.

CHAPTER III

WHEN LIGHT FALLS ON MATTER

When light falls on matter, it is either thrown off from its surface, or enters it. In either case, except where the light strikes at right angles to its surface, a change takes place in the direction in which the light has been moving.

When light is thrown off directly from the surface of matter it is said to be reflected. Light is thrown off or reflected just like a ball bounds off or is reflected from a wall.

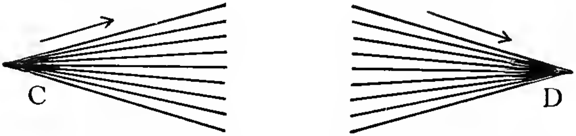
The reflection of light may be regular or irregular. When light is regularly reflected it is generally said to be reflected. When irregularly reflected, it is said to be diffused. The light that enters matter is either quenched as light and changed into heat, or it passes completely through the matter and comes out on some other side.

If a body permits the light to pass through it so readily that objects can be seen through it, as, for example, a plate of clear window glass, it is said to be transparent. If no light passes through the body, the body is said to be opaque, and the light that partially enters it is said to be absorbed. Sometimes a part of the light passes through the body and a part is absorbed. In such cases the light that passes through is coloured, and the body is said to be a coloured transparent body. Sometimes all the light which falls on a body is thrown off from its surface so that the body shines with the same white light as that of the sun. Generally, however, only some of the coloured light is thrown off, and the body is then said to be coloured.

All these peculiar properties of bodies as regards the light that falls on matter will be explained in due course.

A single line of light is called a ray. A number of parallel rays are called a beam, while a number of separate rays, that either collect together at a single point, or proceed outward from a single point, form what is called a pencil.

Ray of Light. Beam of Light.



Diverging Pencil of Light. Converging Pencil of Light

Fig. 1.—Some Common Forms of Light Rays.

In Fig. 1, at A, is the usual conventionalised representation of a single ray of light (the arrow drawn alongside the line indicates the direction in which the light is moving). This is not a correct representation of a ray. That would require a much more complex drawing. A beam of light consists of a number of parallel rays, is represented at B.

A pencil of light consists of a number of rays, that are either diverging as shown at C, or converging as at D.

As you can see, in a diverging pencil the rays are represented as originating or starting from a single point C, and moving outwards away from one another in the direction indicated by the arrow. In the converging pencil, at D, however, the separate rays are represented as all moving towards a single point D, at which they meet.

Let us now take up the subject of reflection. When a single ray of light falls on a highly polished surface such as metal, glass, or on the piece of looking glass with which we were experimenting in the preceding chapter, the light is thrown off from the surface something like a rubber ball is flung off from the wall against which it is thrown.

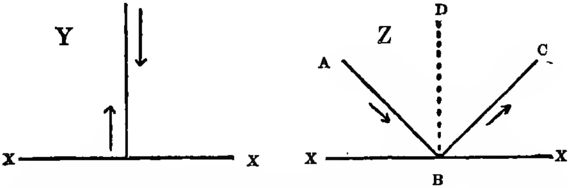


FIG. 2.—REFLECTION OF LIGHT FROM PLANE SURFACES.

If the light strikes the mirror at right angles to its surface, as at Y Fig. 2, it is simply thrown off from the surface so as to move directly back again in the same path in which it was advancing. But if it is inclined to the surface, as at Z, so as to strike it at any other angle, then the light is flung off from the mirror at an equal and adjacent angle to that at which it struck. An examination of this figure will show that if XX represents the surface of the mirror and B the point where the light strikes, then, if we imagine a line DB to be drawn perpendicular to the point B, the angle ABD, or the space included between the direction AB of the ray, and BD, the perpendicular at the point B, where the ray strikes the mirror, will be of exactly the same value as the angle DBC, at which the light is flung off from the surface. The angle ABD is called the angle of incidence, and the angle DBC is called the angle of reflection. These two angles are always equal and adjacent to each other. In other words, as you can see from the figure, the ray AB, striking the mirror at any angle whatever, is flung off from it at an angle that is exactly equal to that at which it strikes.

The reflection of light is so important a matter that I will ask you to make yourself thoroughly familiar with what I have been talking about by an experiment with a piece of looking glass.

Place a piece of looking glass on the surface of a table in a darkened room, and let a ray of sunlight come in through an opening in the shutter, so as to fall on its surface and be reflected or thrown to the wall or ceiling.

In order to be able to see the path taken by the light, you should permit some smoke to fill the air of the room. Since in many of the experiments described in this Wonder Book you will need smoke, I will tell you how you can easily make smoke paper.

Take any kind of paper, but preferably a paper containing but little sizing material, such as a sheet of blotting paper, and dip it in a solution of nitre, or saltpetre, and let it dry. Such paper, when dried, is very inflammable. When touched with a lighted match, instead of burning as a bright flame, it rapidly glows with a red light and produces much smoke. If you ignite a small piece of this smoked paper, loosely wrapped in the shape of a paper lighter, and hold it near the mirror, the space will be filled with finely divided smoke, and a beam of light can be seen both where it enters the room and where it is flung off from the surface of the mirror as shown in Fig. 3. If now you hold a plumb-line and bob C, as shown, so that the point of the plummet points in the direction of the centre of the place where the beam strikes the mirror, but above this place, you can see distinctly the path taken by the beam both before it strikes the mirror and after it strikes it, and you can see that the beam is inclined equally and oppositely to the vertical marked by the plumb-line, so that the angle BAC, the angle of incidence or striking, of one of the rays, is equal to the angle CAD, the angle of reflection, and adjoins it.

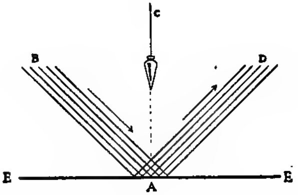


Fig. 3.—Reflection of Beam of Light.

If, instead of employing the smooth and polished surface EE of such a mirror, a rough surface, such as a plate of ground glass BB, Fig. 4, is used, and a beam of light AC be again permitted to fall on the glass at C in the darkened room, then, instead of the light being thrown off in a single direction, it will be thrown off as a great number of separate rays in every direction as shown in the figure. In other words, the beam will no longer be regularly reflected, but will be irregularly reflected; that is, will be diffused or scattered. In order to avoid confusion, only one of the rays of the beam; i. e., that which is incident at C, is shown as being diffused. All the other rays are similarly diffused. You can call this either diffused or scattered light, but please do not say that the light will be dispersed as is some times done, since, as I will afterwards show you, this word is properly used to describe an entirely different phenomenon.

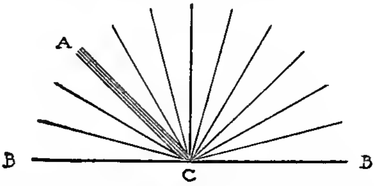


FIG. 4.—DIFFUSION OR SCATTERING OF BEAM OF LIGHT.

You will remember that you can only see an object when the light coming from it enters your eye directly. If, therefore, in any of the preceding experiments you have been able to see a ray, or a beam of light, it was because that ray, while passing through the fine particles of dust in its path, so lighted each of these particles that they diffused or scattered the light in all directions, as represented in Fig. 5. And it was by means of the diverging pencils of light thrown in all directions by the illumined dust particles that you saw the direction in which the light was passing before it fell either on the reflecting or diffusing surfaces and was afterwards flung off from such surfaces.

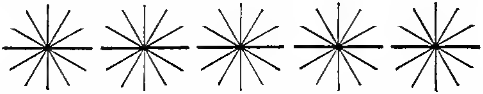


FIG. 5.—PATH OF A RAY SEEN BY DIFFUSION FROM DUST PARTICLES.

If light coming from a small illumined object, such as that represented in Fig. 6, be permitted to enter a dark chamber or box through a small opening in one of its sides, there will be produced, on the side of the box opposite the opening, a small image of the object from which the light has come. Instead, however, of this object being seen in its erect or upright position, it will appear to be upside-down or inverted. In this case, the size of the image will be smaller than that of the object itself, because the object is situated at a greater distance from the hole in the box than is the wall of the box on which the image is received.

I think you can understand why the object should be inverted as well as its difference in size; for, as is shown in the figure, the diverging pencils of light, coming from different parts of the object, passing through the opening in the box, fall on the wall of the box where they form the image. Since the rays from the top of the object form the lower part of the image, and the rays from the bottom of the object form the top of the image, the image will appear inverted as shown. If the box be brought nearer to the object, the size of the image would be increased, and if it be moved away from it the size of the image would be decreased.

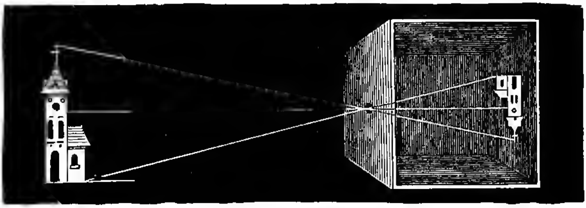


Fig. 6.—Image formed in Dark Chamber by Aperture.

You will see later that the clearness of an image produced in this way will be greatly increased if instead of employing a hole in the dark box, a lens is placed in this hole, thus producing what is known as a camera obscura.

If you make such a box for yourself, which I would advise you to do, arrange matters so you can sit inside it without getting in the way of the light as it passes through the aperture at the end, and so you can see the picture that is thus formed on the side of the box opposite the opening, on a sheet of white paper placed so as to receive it.

An ordinary soap box will answer this purpose. In order that you can see the picture that is formed, remove one of the sides of the box and replace it by a long dark cloth, so that while sitting at one side of the box, you can throw the cloth over your head and shoulders and thus keep the inside of the box dark. To succeed, however, with this experiment, it is necessary that no light enter the box except through the opening in its side.

The smaller the opening in the side of the box the sharper will be the pictures of outside objects. A very small auger hole, bored through the end of the box, would be too large and rough for this purpose. The best results will be obtained if you cover an auger hole with a piece of smooth tin foil, through the centre of which you have pierced a small hole with a large darning needle. You can have no end of fun if you place such a box at the open window of a room, for then you can see on the side of the box opposite the screen an actual moving picture or panorama of everything that is taking place in the street.

If a single luminous point be brought before a white screen, the diverging pencil of light it gives off will uniformly illumine or light it. If, now, a small opaque globe M, Fig. 7, be placed between the screen and the luminous points, since the rays of light that fall on the globe are unable to pass through it, they will be unable to fall on the screen, so that the portions illumined will have the outlines of the outside of the globe, or will form a round or circular shadow. The cause of this shadow is evident. It occupies those parts of the screen from which the light has been cut off by the intervention of the opaque body.

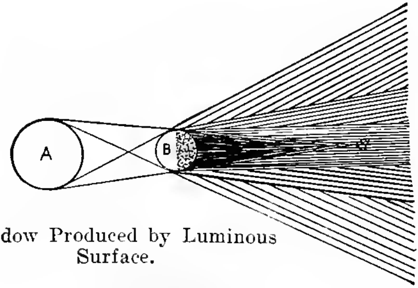
Fig. 7.—Shadow of Sphere Produced by Luminous Point Umbra only Produced.

If you examine this shadow carefully you will see that, practically speaking, all portions of it are equally dark.

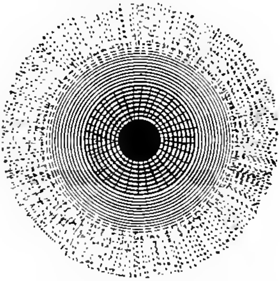
This, however, will not be the case, if, instead of employing a luminous point, a luminous surface is used, as, for example, that shown in Fig. 8. Here A has a sensible surface. Instead of the space back of the opaque body being devoid of light over all parts of its surface, there will be seen a central space, where no light whatever enters, that is surrounded by concentric circular spaces growing less and less dark as we pass from the centre towards the outside: that is, the shadow increases in depth from the outside to the centre where no light penetrates.

Probably many of you know what funny shadow pictures can be produced by holding the fingers of two hands in different positions in front of a candle flame. In order to get the best results in shadow pictures it is necessary to keep the light that is held near the hands in a fixed position.

It is very easy to cut out pieces of paper in irregular outlines with proper apertures left here and there, so as to produce exceedingly curious results in the shapes of shadow pictures on the wall.



Shadow Produced by Luminous Surface.



Cross Section of Shadow Produced by Luminous Surface.

FIG. 8.—SHADOW OF SPHERE PRODUCED BY LUMINOUS SURFACE UMBRA AND PENUMBRA.

It is possible for pieces of paper or leather to be so cut into different shapes as to produce what are known as Chinese Fantoccini shadows. By causing these shadows to follow one another, in proper order, it is possible, especially when aided by conversation, and by suitable movements of the shadows, to tell a story that will be readily understood by the audience. The movements necessary for this purpose are obtained by the movements of the pieces of paper casting the shadows, by the movements of the light, or lights, or by movements of the joints in the pieces of paper.

Interesting forms of shadow pictures are sometimes obtained by means of a suitably turned wooden handle. In Fig. 9 I have shown a piece of wood that, when not in use, was concealed in the top of a cane employed during 1817 for spreading seditious ideas in the city of Paris. I will, however, permit M. Marion, from whose book I have taken the figure, to tell the story of one of these:

"In 1817, one winter's night we were all sitting round the table listening to my father, who was reading aloud an interesting book of the period, when a friend of our family, who had been formerly an officer of the Empire, entered the room. He was a serious, upright, soldierly man, and wore his coat buttoned up to his chin. He had hardly replied to our salutations, when he drew a chair up to the table, and made a sign with his hands and eyes that plainly indicated silence and discretion. There was something in the expression of his countenance that seemed to show that he had something mysterious in store for us, and we fully expected to hear some extraordinary news, or to see him bring out a Bonapartist pamphlet of more than usual importance. Our surprise was consequently great when we saw him slowly unscrew the top of his cane, which was turned out of boxwood, and presented nothing very remarkable either in form or material. He, however, took up a copybook which was lying on the table, placed it at a certain distance from the lamp, and then laid upon it the little piece of turned boxwood. At first we noticed nothing at all extraordinary, and he smiled at our want of intelligence, until at last my younger brother cried out suddenly, 'Look! there's the head of Napoleon!' and truly

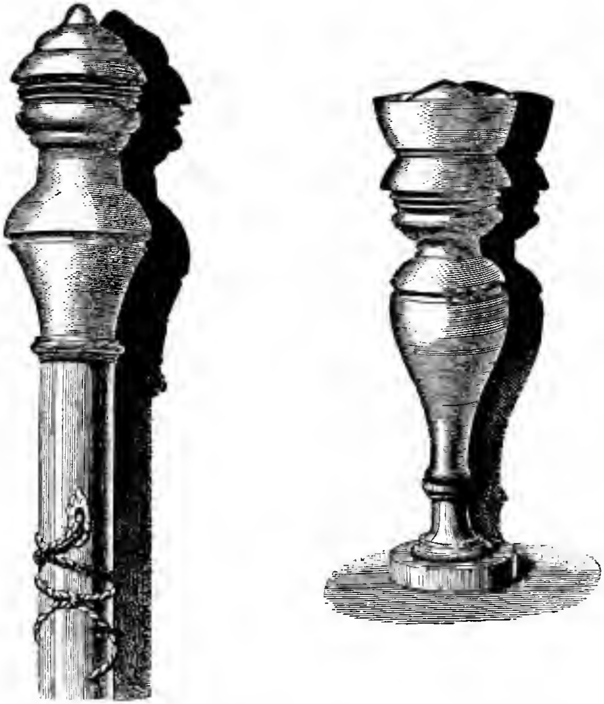


FIG. 9.—PROFILES OF FACES PRODUCED BY SHADOWS.

enough, we found, on looking more attentively at the shadows of the turned knob of the cane, that their profile was that of the great exile, most correctly and clearly portrayed. The old Captain's face lighted up at the sight, and the tears came into his eyes. 'We shall see him again,' he murmured in a low voice, and he hummed the burden of a Bonapartist song then in vogue. During the rest of the evening he was very lively, and proved to us most conclusively that before six months the 'Grande Armée' would be revenged for their defeat at Waterloo. Some weeks after, there was hardly anyone in the town who did not possess a stick or a tobacco-pipe stopper turned in this fashion, but one day a panic seized everybody, and the canes and pipe stoppers were all burnt."

CHAPTER IV

LOOKING GLASSES

In that charming book by Lewis Carroll, "Through the Looking Glass," there are told the odd adventures of a little girl named Alice, who had often seen, back of the looking glass in the drawing-room at her home, another room that looked exactly like the one she was in, except that in the looking-glass room, as Alice said, "things go the other way." Even the books in the looking-glass room had this peculiar appearance, since the letters of the words all went the wrong way.

One day Alice fell asleep, and dreamed that, climbing up on the mantelpiece, she had been able to pass through the looking glass and thus entered the room in which she had so often wished to be. The first thing she did was to examine the little bit of the room, which, being situated immediately under the mantelpiece, she had never been able to see from the other side. Suppose you and I, though much older than Alice, take a peep through a real looking glass and see whether we cannot find out what actually takes place in mirrors that make the images formed in them "go the other way," and especially to see if we can solve the problem of why it is that looking-glass writing has so queer an appearance.

In the first place, let me see if I can explain to you how a piece of looking glass actually produces a change in the direction of the light it throws off from its surface. We will begin with the simple case of a beam of light. Suppose, as at X in Fig. 10, that a beam of light of which 1 and 2 form respectively the lowermost and the uppermost rays, be thrown off or reflected from the surface of a mirror MN. Then, as you can see from carefully examining the figure, owing to the fact that the beam is inclined, after reflection the lowermost ray 1 becomes the uppermost ray of the reflected beam, while the uppermost ray 2 becomes its lowermost ray. Parallel rays of light, reflected from a looking glass, therefore, continue parallel after reflection, but are turned from left to right or from right to left; or, as Alice expressed it, " they go the wrong way."

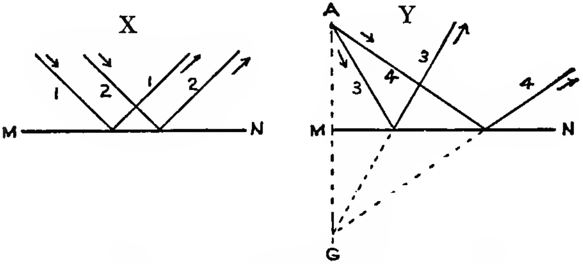


Fig. 10.—Why Looking Glasses make Images " Go the Other Way."

The same is true of a pencil of light diverging from the point A, as shown at Y in the same figure. Here, only two of the diverging rays are shown; i.e., 3 and 4. If this pencil of light be permitted to fall on the surface of a mirror MN, it will be reflected and will continue to diverge after it has been thrown from the surface, the rays taking the direction they would have if, instead of coming from a luminous point A, they came from the luminous point G, situated the same distance back of the mirror that A is in front of it.

If you examine this part of the preceding figure carefully, you will see that here, as in the other case, the rays of light after their reflection from the mirror still keep on diverging, and that 3, the lower ray of the pencil, before reflection becomes the upper ray of the reflected pencil, and that 4, the upper ray, becomes the lower ray after reflection.

Now it is a matter of experience that the position in which an object is seen depends on the direction in which the rays of light, by means of which it is seen, enter the eyes. No matter why this is, it is enough to know that it is so; that is, that you have found it to be so. For example, in the diverging pencil of light, when the rays, after reflection, have entered the eyes of an observer, that is, your eyes or mine placed in front of the mirror, we will not see the luminous point A by the use of the reflected rays, but the image of this point will be situated at G, as far back of the mirror as A is in front of it. It is true that it is possible to see A and G at the same time, but when you see A, it is by means of the rays of light that have come directly from it without having been reflected from the mirror, and when you see the image G, it is by means of the rays that have first fallen against the mirror and then enter your eyes after reflection from its surface.

The same thing is true of the parallel rays, but it will be best to confine our attention now to the case of a diverging pencil of light.

We have taken above the case of a single luminous point. The same thing would be true if we take an illumined object, such, for example, as the arrow shown in Fig. 11. Here, from all points of the arrow, small diverging pencils of light fall on the mirror and enter your eye. After reflection the diverging pencil from the point A, of the arrow, entering the eye as shown, appears to you to be situated at *a*, while the pencil from B, the feathered end of the arrow, after reflection, enters your eye, producing the image *b*. As you see, the image *ab* appears to be situated back of the mirror at exactly the same distance that the object AB is in front of it. Now as regards this image, it is evident:

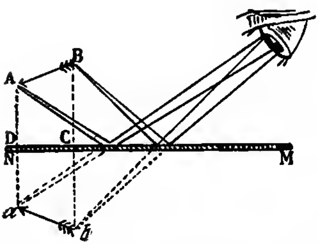


FIG. 11.—A LOOKING GLASS IMAGE.

(1). That it occupies an entirely different position from that of the object; for, it is back of the mirror.

(2). There is something odd about its appearance for, being situated back of the mirror, it seems to go "the wrong way"; for, now, all the rays from the point of the object which before reflection were uppermost, as shown at 1, are now lowermost, while the lowermost ray 2 is uppermost after reflection. Therefore, the image is caused to assume the curious appearance that images always do in looking glasses, and this is the reason why everything looked so odd to Alice in the looking glass room.

Can you read the writing on the slip of paper represented in Fig 12? No, it is not a foreign language; it is simply English written in looking-glass style. I wrote a certain phrase on a slip of paper in ink, and then, while the ink was still wet, I laid a piece of blotting paper on it, and in this manner took off an impression of the wet ink on the blotting paper. It is this impression you are looking at in the above figure. It is true neither the words nor the letters present the same appearance they ordinarily do, but that is because they have been made to go the "wrong way," just as they would have gone had you taken them off, not on a sheet of paper, but on the surface of a looking glass by holding it in front of the writing.

If you have difficulty in deciphering the writing in Fig. 12, hold the paper containing it in front of a looking glass, and see how easy it is to read from the image in the glass, the words "The Wonder Book of Light." The looking glass completely undoes what the method of transferring the image to the paper did.

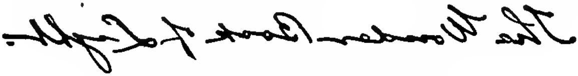


FIG. 12.—LOOKING GLASS WRITING.

If you think carefully over what I have just said, remembering all the time that the sheet of blotting paper has produced the same effect on the appearance of the writing that is produced by a looking glass, the difficulties of understanding the way in which a looking glass acts on images will, I think, disappear. Such a matter would be much less difficult for a printer to understand, since, as he knows very well, it is necessary to set type for printing in this same backward, looking-glass style, so that, when the surfaces of the type are inked, and an impression is taken off from them, the characters will appear in the everyday manner with which we are so familiar. The printer, however, accustomed as he is to read this kind of writing, has no difficulty with it.

A looking glass produces no change in the size of the image over that of the object. This you can convince yourself of by standing in front of the glass, say in your bureau or wardrobe, and looking at your own image. As you can see, its size is exactly the size of your body.

Instead of looking at your own image in the glass, look at the images of the fixed objects in the room, say the image of a chair or a bedstead. You can see these images from different parts of the room, but no matter how you may move about from place to place, their position remains fixed. They will always be seen in the mirror at a distance back of it exactly the same as their distance in front of it.

Now again look at your own image in the mirror and notice what happens as you walk towards or from the mirror. Your image does the same thing. It walks further away from the mirror, or nearer to it, as you do.

Of course all these images are inverted in looking-glass fashion. I will only say one thing more about this peculiarity and then I am through with it. The difficulty is that we have become so accustomed to looking-glass images, that, in most cases, we fail to note any peculiarity about them unless we hold up a printed page and then we cannot fail to see the curious change in the appearance of the letters. As far as our own image is concerned, you have seen it so often in a looking glass that it seems all right, but if you will think a moment, you will see that the image of your right eye appears directly in front of this eye, and the same is true of other parts of the body, a thing that could not possibly be true were not the images of these parts inverted in looking-glass style.

Of course you know, when a number of people are in a room, their images can all be distinctly seen by every person in the room, though, of course, by entirely different rays of light; for, it is only the rays of light that enter the observer's eye that permit the objects to be seen, and these rays of light are completely used up in producing impressions on the brains connected with the eyes through which they have passed.

In "The Wonder Book of the Atmosphere," I have briefly explained the cause of echoes. An echo is a repetition of a sound produced by reflection from an object at a sufficient distance to permit the direct sound to die away before the reflected rays entering the observer's ear again produce the sound. Echoes closely resemble the sounds that produce them. They are, however, fainter than such sounds.

Now an echo can be regarded as the image of a sound. The reflecting wall or surface, sometimes a huge perpendicular cliff, acts as a kind of acoustic looking glass, that, by flinging the sound waves back to the observer, enables his ear to *see* the image of the sound as far back of the cliff as the true sound was in front of it.

In a similar manner, a looking-glass image may be regarded as a kind of luminous echo, closely resembling the illumined object, but being much less bright.

The cause of the decreased loudness of an echo and the decreased brightness of an image are practically the same; i.e., the loss of light or sound by reflection.

While, as we have seen, light always travels in straight lines, so that visible objects are cut off from view by the interposition of a book or other opaque object between the eye and the object, yet since it is easy to change the direction of light by reflection from mirrors, it is not difficult in this manner to be able to look not only around corners, but even underneath an object. In this way objects can be easily seen that would otherwise be invisible. For example, in Fig. 13, there is represented a divided form of telescope.

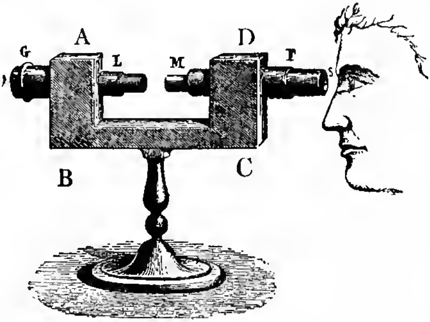


FIG. 13.—APPARATUS FOR LOOKING THROUGH A MILLSTONE.

Now no one would be surprised if, looking through the proper end of the telescope S, an object is seen in the direction G in which the telescope is pointed, for this is what a telescope is made for. Of course you can see through it if you look in the proper direction.

I am sure, however, you would be considerably surprised if, when some unquestionably opaque object, such as a brickbat, be placed in the space between the two halves of the telescope, you could still see the distant object quite as distinctly as before; for here you are apparently looking directly through a brick.

I have heard people say when asked to look at something which it was clearly impossible to see, "Do you think I can see through a millstone?" Well, I won't answer that question directly. I will simply say that if a millstone instead of a brickbat were placed between the two halves of the telescope, or, indeed, any opaque object were so placed, no effect whatever would be produced on your ability to see a distant object at which the glass has been directly pointed.

Of course the explanation is simple. You are not looking through a brick, or through a millstone, or any other opaque object. You are simply peeping down the side of the brickbat nearest you, underneath it and up the further side, so that there is nothing odd about it unless it is in the ingenious manner in which you have been able to cause your eye thus to dodge the obstacle.

Let me explain how very simple this contrivance really is. All that is needed are four pieces of mirror or looking glass placed as shown in Fig. 14. One of these, A, is placed as shown on the side farthest from the eye. A ray of light coming from the object at which the telescope is pointing, falling on the mirror A, is reflected from it. After having passed downwards to a point below the brickbat or millstone M, it falls on the surface of the mirror B, and is reflected in a horizontal direction to the surface of the mirror C, from which it is thrown upwards only to be received by the fourth mirror D, which enables it to pass through the other half of the telescope and so enter the eye of the observer.

It is astonishing how many things that at first sight appear to be wonders or marvels are explained by the ease with which a mirror may change the direction in which light passes. Suppose, for example, people inside of a besieged garrison wished to obtain a better view of the movements of the enemy outside than can be obtained by looking through a loophole. Of course, they could go on top of the ramparts where they could see everything, but since there would probably not be enough left of the observer to take any valuable information to those inside if the enemy's gunners were good marksmen, such an exposure would be foolhardy in the extreme. It would be silly, because a looking glass could do this work quite as well as, if not better than, a man. It would only be necessary to support a mirror suitably above the ramparts and permit the light reflected from it to fall on the face of a second mirror placed below it inside them. Thus a man inside could see whatever is going on on the outside.

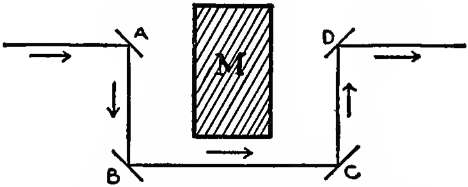


Fig. 14.—Arrangement of Mirrors in Fig. 13.

At the theatre opera glasses are levelled at the stage, without arousing surprise, for the players expect to be looked at. Indeed, people in the audience do not greatly object to this. But excitement and disagreeable developments might result if one should persist for a half hour or so in deliberately levelling his glasses at one particular box. By simply placing a mirror in a pair of opera glasses, matters can readily be arranged so that they, when apparently pointed at the stage, are in reality pointed at some particular part of the house that the persons who are using the glasses desire especially to observe.

In a similar manner a person using coloured glasses to protect the eyes from the sun can easily so adjust the glasses as to be able to see what is going on in back of them, so that the very common expression, "Do you think I have eyes in the back of my head?" might be answered: "No, but I strongly suspect you have what amounts to practically the same thing, mirrors in your eye glasses that enable you to see what is going on back of you as well as in front."

There is a curious variety of plane mirror known as the Japanese magic mirror. While ornamented on the back with various Japanese characters, hieroglyphics, flowers, birds, or other things, its reflecting surface consists apparently of an entirely smooth mirror-like surface. It seems to be continuous, even, indeed, when examined through a powerful magnifying glass.

This even surface of the mirror, however, is only apparent, for, if the mirror is held in a darkened room so that a diverging pencil of light from an electric lantern can fall on it, and is thence reflected to a distant screen, instead of an evenly illumined disc that would have been produced were its surface absolutely uniform, there will be seen over its surface the same Japanese characters, hieroglyphics, etc., that ornament its back.

I understand that the cause of this curious phenomenon is not entirely understood. In some manner the designs placed on the back of the mirror have been permitted to extend through from the back to the front without, however, leaving any traces of their existence. While the front of the mirror appears to the eye to be absolutely uniform, yet this uniformity is unreal, for when the light falls on it, the structure is revealed in the image that appears on the screen.

Sir David Brewster suggested that the explanation may possibly be as follows: That the design has been carefully engraved on the surface of the mirror, and this surface then carefully ground and polished in such a way as to leave the engraving invisible, but still to leave sufficient traces of it to permit them to act on the light emitted from its surface.

A more probable explanation is that the images are caused by molecular changes in the surface due to hammering or to a peculiar method of casting.

Another explanation suggested by Mr. Ives, of Philadelphia, as the result of an investigation of somewhat similar figures produced by the reflection of light from a brass button, attributes the cause of the images to slight irregularities in the surface of the mirror; for he found that, if a button that gave a good image was ground and polished, all its magical images instantly disappeared, being replaced by a plain bright disc. Mr. Ives expresses the belief that the curious properties of the Japanese mirror were in the first instance produced accidentally, so that "our former estimate of the Japanese metal-workers' ingenuity may be taken *cum grano salis.*"

When instead of a single mirror two or more mirrors are employed, there will be produced more than a single image of any object before them. Suppose, for example, two mirrors are placed at right angles to each other. Then three images of any object, such as a lighted candle and candlestick, placed before such a mirror will be produced. Moreover, the number of images seen in two plane mirrors will vary with the inclination between them. If, for example, the mirrors are inclined to each other at an angle of sixty degrees, five images will be produced. If inclined to each other at an angle of forty-five degrees, seven images will be produced.

When the mirrors are parallel to each other, a great number of images are produced. Indeed, it can be shown, theoretically, that if the mirrors were absolutely parallel to each other, and no light were lost by reflection, the number of images that ought to be seen would be infinitely great. In point of fact, however, so much light is lost by reflection that after a certain number of images have been produced no more are seen owing to their feeble illumination. Then again, it is a very difficult matter to place mirrors so that they are exactly parallel to each other. The slightest deviation from parallelism will result in the images being formed a trifle out of the perpendicular, so that at last the curvature becomes too great to permit the images to be seen. In such cases, the images disappear long before they would on account of lack of illumination.

You have probably seen the effects produced by reflection from parallel mirrors in the case of mirrors placed on opposite sides of a room, or, especially, on the opposite side of an entry or hall. Here, by looking into a mirror on either side, you can see a great number of rooms opening out from one other, in the dim distance, until they become too faint to be seen any further.

Some idea of the numerous images formed by parallel mirrors can be had from an inspection of Fig. 15. Here an object O is placed between two mirrors, the reflecting surfaces of which face each other as shown. The first reflections form the images a_1 o_1. The second reflections form the images a_2 o_2. These are the images of the images. The third reflections form the images a_3 o_3. No attempt has been made in this figure to show the paths of the reflected rays except for the third image.

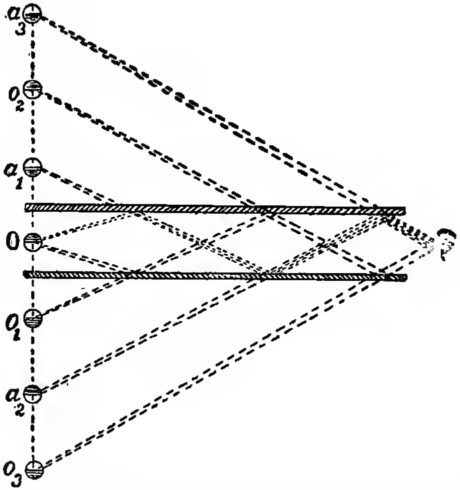


Fig. 15.—Multiple Images of Parallel Mirrors.

In "The Wonder Book of the Atmosphere," in speaking of echoes, attention was called to what were called multiple echoes. Here, the source of sound was situated between the two parallel reflecting surfaces, so that when the sound waves were thrown alternately between the two surfaces, they produced multiple echoes. As you now see, multiple images are formed in the same way.

A beautiful piece of optical apparatus called the kaleidoscope depends for its operation on the images produced by two mirrors that are inclined to each other. The kaleidoscope was invented by Sir David Brewster. He called the instrument a kaleidoscope. The word is formed of three Greek words meaning " to see beautiful forms."

In the kaleidoscope, two mirrors are inclined, with their reflecting surfaces facing each other, at an angle of exactly 60°, and the objects whose images are to be reflected are placed in the space between the two plates. These objects consist for the greater part of coloured glasses or other conspicuous small objects.

The kaleidoscope may be constructed as follows: Two glass mirrors, in the shape of strips, are placed inside a pasteboard tube of the same length as the glass, with their reflecting surfaces facing and inclined to each other at an angle of exactly 60°. One end of the tube, the end at which the eye is to be placed, is closed by means of a metallic plate provided at its centre with a small circular opening for the eye. The other end of the tube is provided with two plates. That on the outside is formed of ground glass, and the other of clear glass. Small pieces of glass, coloured beads, rods, or cylinders, are placed in between the two glasses. If now the tube is pointed towards a source of light, the coloured objects will be illumined, and if the eye is placed at the other end of the tube, the images will be seen arranged in symmetrical groupings. When the tube is slowly turned, so as to produce different groupings of the objects, a succession of symmetrically grouped images of wonderful and beautiful patterns will be seen.

In order to insure the symmetrical arrangement of the images, the angle of inclination between the mirrors must be such a number of degrees as will exactly divide an entire circle, 360°, such, for an example, as 60°, 45°, etc. 60°, however, is almost always employed for kaleidoscopes.

The more usual form of kaleidoscope is made with three glass plates extending the length of the tube instead of the two above referred to. Here each pair of plates acts as a kaleidoscope, so that the combined effect is the same as if *three* separate kaleidoscopes were employed.

The kaleidoscope is sometimes employed by designers in order to obtain satisfactory combinations of colors, symmetrically grouped, as designs for wall papers, floor coverings, and other similar objects.

CHAPTER V

BURNING GLASSES AND SHAVING GLASSES

Besides mirrors that are straight or flat, like ordinary looking glasses, there are curved mirrors of various outlines, such as portions of spheres, egg-shaped bodies, cylinders, cones, etc. In fact any curved body, whatever its shape, if made of a suitable reflecting material, is capable of acting as a curved mirror.

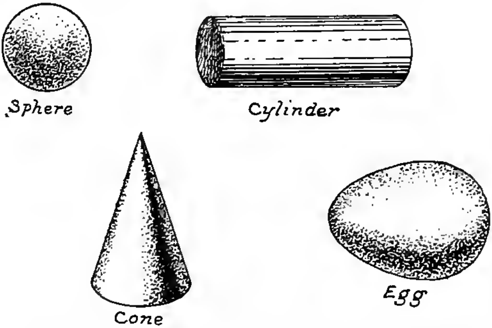


Fig. 16.—Differently Shaped Bodies that can be Employed as Mirrors.

In curved mirrors reflection may take place from either the outside or the inside surfaces. Mirrors can, therefore, be divided into two classes; i. e., convex mirrors, in which the reflection is from the outer curved surfaces, and concave mirrors, in which the reflection is from the inner curved surfaces.

But before going any further, let me see if I cannot make clear to you just what the words concave and convex mean. When a solid is arched or vaulted, its upper surface is said to be convex. In other words, when an object has a convex shape it bulges outward. For example, in Fig. 16, you will find represented a sphere, a cylinder, a cone and an egg.

Limiting our attention first to the sphere and the egg, you can see that the outer surfaces of both of these bodies are arched, vaulted or bulged outwards, that is, their outer surfaces are convex surfaces. So, too, is the outer surface of the rounded portion of the cylinder or stovepipe.

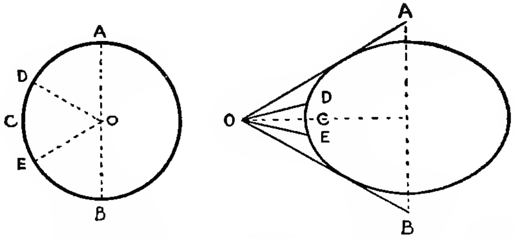


Fig. 17.—Sections of Concave and Convex Mirrors.

A concave surface, on the contrary, has a curved or rounded inner surface, such as the inside of a hollow sphere, or of the shell of an egg cut in two and emptied of its contents, or as is the inner surface of a cylinder or stovepipe.

Suppose, now, the outside of the sphere, cylinder, cone or egg, represented in Fig. 16, be covered uniformly with some smooth and highly polished reflecting material, say, silver. Then such surfaces would act as convex mirrors. And, in the same way, if these bodies were so cut in pieces as to be able to get at the inside, and the inside surfaces were coated with a smooth, reflecting material they would form concave mirrors.

In actual practice, instead of using one half ACB, of either the inside or outside surface of the sphere or egg-shaped body shown in sections in Fig. 17, only a small portion, or segment, of this surface is employed, as DCE.

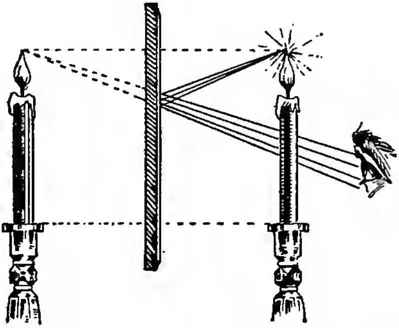


FIG. 18.—POSITION OF IMAGE FORMED BY PLANE MIRRORS.

Such segments or pieces, when covered with reflecting material on the outside, would form convex spherical mirrors, and with this material on the inside, would form concave spherical mirrors.

Curved mirrors, whether convex or concave, are capable of forming images that differ from the images formed by plane mirrors, in that although they are sometimes the same size as the object, yet are generally of a different size; i. e., either larger or smaller. Moreover, unless care be taken in the construction of the mirror, especially in seeing that its surface has been formed by employing a small portion only of the sphere or the egg-shaped body, the images do not, as is always the case with plane mirrors, closely resemble the shapes of the objects, but present curious contortions, producing images of very odd or grotesque forms that in the case of the images of people are often extremely ludicrous.

FIG. 19.—AN IMAGE FORMED BY A CONCAVE MIRROR.

There is another respect in which the images produced by curved mirrors differ markedly from those of plane mirrors. In plane mirrors the images are always formed at a distance back of the mirror exactly equal to the distance the object is in front of it, as for example, in Fig. 18, which represents the image of a candle placed in front of a plane mirror. As will be seen, the rays of light enter the eye of an observer in front of the mirror, as though they came from another candle placed back of the mirror at the same distance the real candle is in front of it. You will notice here that the image is erect, although, as I have shown you, it is inverted from one side to another. It is also much fainter than the object, owing to the light lost by reflection.

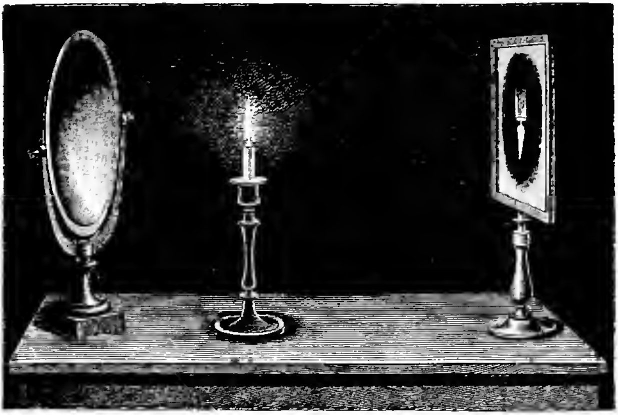


Fig. 20.—Another Image of Concave Mirrors.

Now, in the case of a curved mirror, the image may fall either back of the mirror, as represented in Fig. 19, or it may be formed on the same side of the mirror as the object is situated, as shown in Fig. 20.

You will observe, however, by carefully examining the above figures, that in the first, where a lighted candle is placed in front of a concave mirror, while the image appears both in its upright or true position on the other side of the mirror as it would if it had been a plane mirror, that the image is not the same size as the object, but is larger, and that, moreover, it seems to be situated at a shorter distance back of the mirror than the object is in front of it.

In the case of the second figure, where the lighted candle is placed in front of a concave mirror, its image, as received on the screen shown at the right-hand side, is magnified and is seen upside down, or in an inverted position.

Before going any further, I wish to explain the meaning of the word focus, as it is used in optics in connection with mirrors and lenses. If a beam of light, by which you will remember is meant a collection of parallel rays, such, for example, as exist in sunlight, be permitted to fall on the surface of a concave mirror, as shown in Fig. 21 at A, then after reflection the rays will collect at a single point or focus F, called the principal focus, as being the focus of the principal source of light; i. e., sunlight.

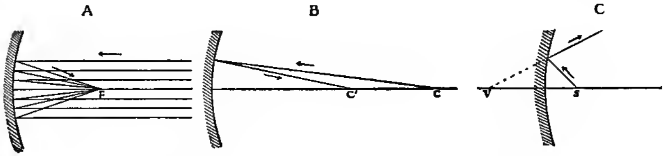


FIG. 21.—THE FOCI OF CONCAVE MIRRORS.

If the luminous point be placed, as at B, at any other point C, at a greater distance than the centre of the sphere of which the mirror is a part, that is the centre of curvature, then its focus will be found at C′, at a distance from the mirror less than the centre of curvation. These points are interchangeable. If C′ is made the luminous point then C becomes the focus. Such foci are therefore called conjugate foci.

If, however, the luminous point is placed as at C, at S, much nearer to the mirror, then the rays after reflection, will not come to any point in front of the mirror, but will seem to come from a point V, back of the mirror. This point is called a virtual focus, because it is not real, but is only apparent.

I shall not attempt to go any further into the difficult subject of the foci of mirrors. It is sufficient to know that all mirrors, whatever their shape may be, possess foci that are either real or virtual.

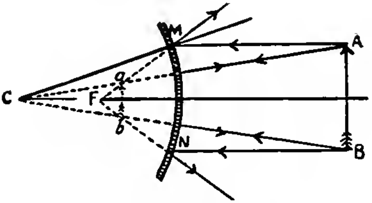


Fig. 22.—Image formed by Convex Mirrors.

A very common use of a concave mirror is for a purpose my boy readers will appreciate more than the girls; that is, they are used for shaving glasses. To use such a glass, it is only necessary to bring the face near its silvered concave surface, so as to produce an erect magnified image of the face and whatever, perchance, may be on it. Of course, I can imagine I hear you laughing and saying that it will be some time before you will have use for such a glass, which, of course, may or may not be true.

Convex mirrors generally produce images such as shown in Fig. 22. Here, you can see the manner in which the image is formed by the rays of light as they are reflected or thrown off from its surface. The image is erect and smaller than the object.

If you are unable to obtain a well-formed concave or convex mirror you can get fairly good results from the outside or the inside of any highly polished silver dessert or table spoon; for, if you employ the hollowed bowl of the spoon, you will find it acts capitally as a concave mirror, and will produce a fairly clear magnified image of your face. Since, as you know, the bowl is not of the same curvature in all parts, you must expect the image to be twisted or contorted. This, however, will only result in giving the image of your face a ludicrous appearance. In a similar manner, you can obtain an image of your face by holding the outside of the bowl of the spoon in front of you. A soap bubble can also be used as a convex mirror. Here, so large a portion of the surface is employed that the images will be greatly distorted.

Brightly polished ice pitchers, soup ladles, soup tureens, butter dishes, and other pieces of silverware, often give grotesque and amusing images of the face or other parts of the body seen in them.

Get a silvered glass ball like the ones that grow on Christmas trees, and show your friends how comical they look when seen by the light reflected from its convex surface. As I told you, in order to obtain correct outlines in spherical mirrors, it is necessary to employ only a small portion of the sphere.

The focus or place where the sun's rays collect in front of a concave mirror is a point of considerable heat, especially if the mirror is a large one.

Fig. 23 represents a huge concave mirror, employed as a burning mirror, supported in the required position on a platform mounted on wheels. When such a mirror is turned towards the sun, on a day when the sky is clear or free from clouds, the rays after reflection, when collected at the focus of the mirror, will immediately set fire to a pile of wood or other combustibles, provided, of course, the mirror has been placed so as to make its focus fall directly on the pile.

Buffon, the French naturalist, constructed a huge concave mirror that was capable of producing some very remarkable results when used as a burning glass. Owing to the large size of the mirror, the amount of heat collected at the focus was so great that it would almost instantly raise refractory substances to brilliant incandescence; while heavy logs of wood, which, as you know, are very difficult to start burning, almost instantly burst into flame when brought into the focus.

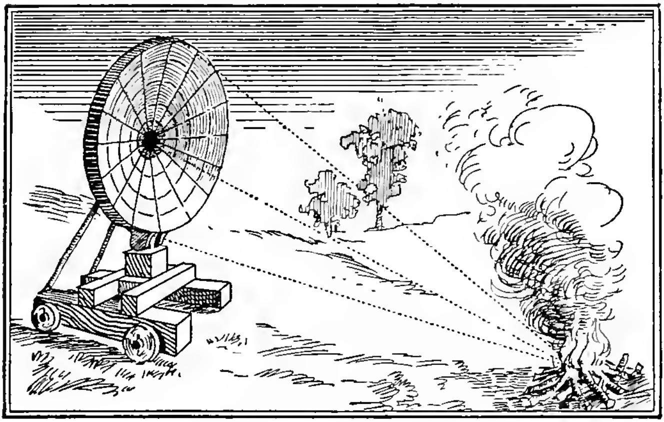


FIG. 23.—BURNING MIRROR.

Archimedes, the Grecian philosopher, employed a burning mirror for setting on fire the ships of the Roman fleet, when, having besieged Syracuse, they approached within bowshot of the fortifications.

Some very curious effects are obtained by the use of cylindrical mirrors. When the convex surface of the cylinder is employed, the image of a person can be seen in certain positions in correct dimensions in one direction, but very much contorted in the opposite direction. The result is that a curious change in appearance is produced.

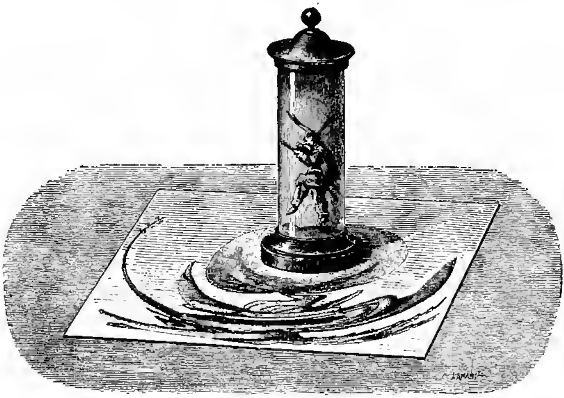


FIG. 24.—CURIOUS EFFECT OF CYLINDRICAL MIRROR.

In one direction, a person appears to be lengthened out in a remarkable manner. In another direction, he appears to be greatly increased in girth and decreased in height. If you ever have an opportunity of obtaining a mirror of this character, you can show your friends how odd they will look in after years when they have taken on weight and become round, and fat, and jolly, or how they might look should they grow too thin.

You can form some idea of the deformations produced by cylindrical mirrors by examining the exceedingly odd looking figure represented on the sheet of paper on which the cylindrical mirror shown in Fig. 24 is resting; for this figure when examined in the cylindrical mirror produces the image you see represented in the mirror.

The inner surface of a teacup with fairly vertical walls is capable of acting as a concave cylindrical mirror not unlike the convex cylindrical mirror of the preceding figure. And, moreover, the surface of coffee or tea in the cup forms an admirable screen on which to receive the image. If, therefore, some time when your tea or coffee cup is only half filled, you so place it that the light from a distant burner in a chandelier is reflected from one side of the cup you will see, thrown on the surface of the coffee or tea, a curious double curve produced by reflection from the inside of the cup.

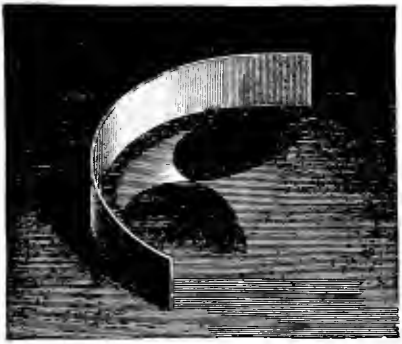


Fig. 25.—Curious Double Curve formed by Concave Cylindrical Mirror.

If you employ a strip of the zinc such as is used for placing under stoves, you can obtain some of the effects produced by cylindrical mirrors. For example, if you place it, as shown in Fig. 25, on a sheet of white paper, you will obtain the appearance represented, which will be the same as that seen in the tea or coffee cup before referred to from the reflected light of a gas burner or lamp placed anywhere in front of it.

CHAPTER VI

THE BENDING OR REFRACTION OF LIGHT

As we have already seen, when a beam of light falls on a transparent medium, a portion of the light is thrown off or reflected from the surface, and the remainder entering the medium undergoes a change in the direction of its path known as refraction. In the case of such transparent substances as water, by far the greatest proportion of the light enters them and is refracted. It can be shown that the smallest proportion of the light is reflected, and the greatest amount is refracted or passed into the water, when the light falls directly on the surface, that is, strikes it perpendicularly.

In this case only eighteen rays out of every thousand are flung off or reflected, the remaining 982 rays passing through the water.

If the beam of light is permitted to fall more and more obliquely on the surface of the water (that is at a greater slant) the amount of light reflected from its surface will be increased, and, consequently, the amount that enters the water, or undergoes refraction, will be decreased.

Tyndall has shown that out of every 1,000 rays the amount of light that is reflected and refracted for different angles of incidence is as follows:

Angle of striking.	No. of rays reflected.	No. of rays refracted.
0°	18	982
40°	22	978
60°	65	935
80°	333	667
89° 30′	721	279

In other words, as the rays fall more and more obliquely on the surface, the amount of light reflected becomes greater and the amount refracted becomes less.

During mid-day, when the sun is almost directly overhead, it is possible to look directly at its image in a body of water acting as a huge mirror, for then, the rays striking the surface almost perpendicularly, the number of rays that are reflected is comparatively small. If, however, you should attempt to look at the sun either near sunrise or sunset, when the rays fall obliquely on the water, the amount of light flung off from the surface is so great that your eyes would be dazzled.

When a beam of light is permitted to fall on an opaque substance, such, for example, as on the surface of a sheet of polished metal, a small quantity of light enters the substance and undergoes refraction, while the remainder is reflected or thrown off from the surface. The quantity of light that can enter an opaque substance is quite small.

In Fig. 26, a beam of light is permitted to fall obliquely on the surface of a glass vessel nearly filled with water. As you see, this vessel is placed on a table in the path of a beam of light entering a darkened room through a hole in the shutter. Generally, the path of the beam before it strikes the surface of the water can be easily seen by the beam lighting up or illumining particles of dust that are scattered through the air. It might be well, however, to ensure the beam being seen by burning a piece of smoked paper, so as to make the air of the room smoky.

You will notice that the beam continues to move in a straight line until it strikes the surface of the water, when it is bent out of its course as can be seen while it passes through the water.

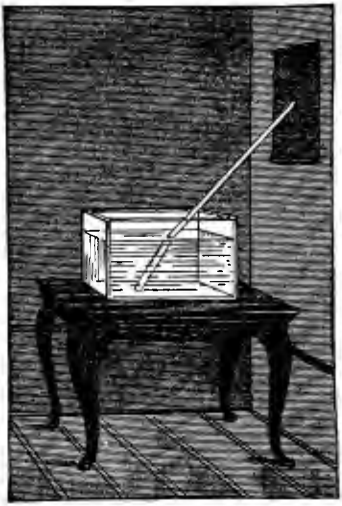


FIG. 26.—AN EFFECT OF REFRACTION

You will also notice that the change in the direction of the rays takes place only at the surface of the water where the air comes in contact with it. While the beam is passing through the water, it continues its straight course just as it did while passing through the air, but its path through the air and through the water does not continue in one and the same straight line, being bent as already mentioned, where the water surface touches the air. Now it is this bending that is called refraction.

Refraction, like reflection, is an important property of light, and on it depend many of the wonderful things that we shall see when we come to study the phenomena of light.

Let us now examine more carefully what takes place when light falls obliquely on a water surface. For the sake of simplicity we will take the case of a single ray of light in place of a beam. Suppose then that RI represents a single ray of light passing from R to I, where it falls on the water surface represented in Fig. 27. Had the water not been present, the ray RI would have continued on in a straight course RIR′; but, meeting the water, it undergoes refraction, and takes the path IS through the water, being turned out of its course as shown.

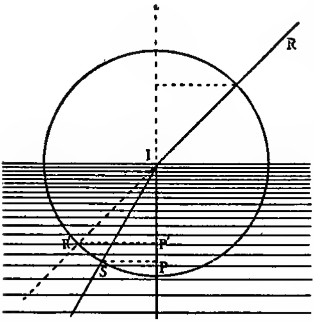


Fig. 27.—Refraction of Light.

It is not my intention here to enter into a full explanation of all the peculiarities of the refraction of light. The subject is very difficult. If, however, you examine the preceding figure you can easily see that the angle included between the direction of the refracted ray IS and of the perpendicular at the point of incidence is smaller than the angle between the same perpendicular and the direction the ray RI had when it struck the surface of the water. In other words, when light passes from air to water, it is so refracted or bent that its inclination to the perpendicular is less than it was before refraction occurred.

Now the proportionate amount a ray of light is bent out of its course by refraction, while passing between any two media, such as air and water, always remains the same for these media. If, therefore, we know the direction in which light falls on a water surface, it is possible to calculate the path it will take after refraction.

I would say here for the older reader that the constant ratio existing between the angle at which the light falls on the surface and the angle at which it is refracted (or, more correctly, between the sines of these angles, represented in the preceding figure by dotted lines) is known in optics as the index of refraction. In other words, the index of refraction is equal to the sine of the angle of incidence divided by the sine of the angle of refraction.

Now the proportionate amount that a ray of light is bent out of its course by refraction, while passing between any two media, such as air and water, always remains the same for these media. Therefore, knowing the direction in which light falls on a water surface, it would be possible to calculate the path it would take after it underwent refraction; for, there is always a constant relation existing between the angles at which the light falls on the surface and the angle at which it is refracted, this ratio being known as the index of refraction.

I would say here for the older reader that the ratio above referred to is not that of the angles of incidence and refraction themselves, but of certain quantities known in trigonometry as the signs of these angles, and represented in the preceding figure by the dotted lines R′P′ and SP. The index of refraction, therefore, is equal to the sine of the angle of incidence divided by the sine of the angle of refraction. The further development of the equation is beyond the scope of this book.

If a ray of light is passed from water into air it will also undergo refraction as soon as it reaches the bounding surface between the water and the air. If, for example, SI in the preceding figure, represents the direction of a ray of light passing through the water from S to I, then when it reaches I, at the surface between the water and the air, it will be refracted, and will take the path IR. In this case the ray will be bent away from the perpendicular. When, therefore, light passes from a medium like air to a denser medium like water, it is refracted in such a direction that it is bent towards the perpendicular, so that the angle of refraction is less than the angle of incidence, but when light passes from a dense to a rarer medium, as from water to air, the refracted ray is then bent from the perpendicular.

It can be shown that the reason for the bending or refraction of a ray of light when passing from one medium to another is the difference in the velocity of the light in passing through the two media. The extent of bending depends on the difference of this velocity in the media. In other words, the refracted ray is bent *towards* the perpendicular when the light passes from air to water, and *from* the perpendicular when the light passes from water to air, because the light travels less rapidly through a dense medium like water than it does through a rare medium like air.

I have already called your attention to the fact that the position of an object depends on the direction in which the rays of light coming from the object enter the eye of an observer. Now, since refraction alters the direction in which the rays of light coming from an object in a medium such, for example, as water enter the eye of an observer placed in the air over the water, it is evident that the apparent position of the objects will be changed by refraction.

There is only one direction in which a person can see an object in water in its true position; this is when the rays of light coming from the object do not undergo refraction, or when they strike perpendicularly on the surface. But this is the same thing as saying that in order to see the true position of an object in water the eye of the observer must be situated directly over the surface of the water; for if the eye is placed to one side, when the light coming from the object under the water is refracted while passing through the air and enters the eye of the observer, it makes the object seem to be elevated or brought nearer the surface.

Suppose, for example, that A, Fig. 28, at X, represents an object placed on the bottom of a stream of water whose surface is situated at FF. Then if 1, 2, represent a diverging pencil of light coming from A, its rays, on passing into the air will undergo refraction, and take the path represented by 3, 4. These rays entering the eye of an observer, would seem to come not from the true position of the object A on the bottom, but as if both it and the bottom had been raised to occupy the position B, so that the water appears shallower. If, therefore, A were a fish and not a stone, an air-rifle aimed at the apparent position of the object at B would fail to strike it (that is, if aimed correctly), for it would strike considerably above the true position of the object. It is for this reason that due allowance must be made in attempting to strike an object when viewed under water for change in position caused by refraction.

You can easily try an amusing experiment in refraction in the following manner. Place a quarter of a dollar at *m, n,* Fig. 28, at Y, on the bottom of a vessel that contains no water, and then stand with the eye at O, so that the light coming from the coin is just cut off by the upper edge A of the basin, and the coin is, therefore, invisible. Now, holding the head in a fixed position, get some one to pour water in the basin and you will find that as soon as the water reaches about the level PP′, the coin will become visible, without your having had to move your head.

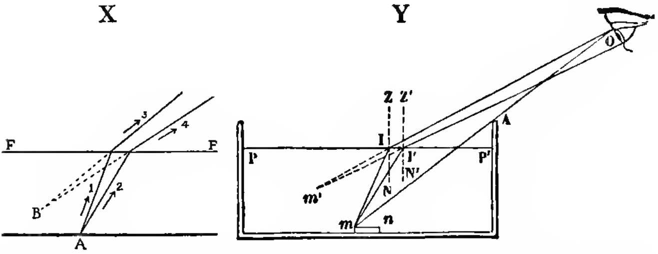


FIG. 28.—EFFECT OF REFRACTION OR APPARENT DEPTH OF WATER.

The explanation is evident. The rays of light coming from a point of the coin at *m,* although they continue in a straight path while passing through the water are refracted or bent out of their direction as soon as they enter the air, and, being bent towards the eye as shown in the above figure, appear to come from the coin as if it were situated not at *m,* but at *m′.* In other words, refraction has not only made the vessel of water appear to be less deep, but apparently raised the coin from *m* to *m′*, and has so enabled you to see it.

There are a number of common phenomena that are due to the bending of a ray of light at the bounding surface between media of different densities.

If you rest a straight stick in the air, against the ground or the pavement, it will loook straight all the way from the top to the bottom, for there is nothing to change the direction of the rays of light as they come from its different parts between the top and the bottom and enter your eye. If, however, the stick is plunged into a stream of clear water, so as to rest against the bottom, with a portion in the air, it will appear to have been broken at the point where it enters the water. Its lower end will seem to have been raised so as to make the water appear less deep than it really is; and, since the portion of the stick that is out of the water has not had its appearance changed, the portion under water thus appears to be bent at the point where it enters the water surface. I think you will have no trouble in understanding the cause of its broken appearance by carefully examining the direction of the rays as they pass from the water at the lower part of the stick into the air.

Some very curious effects are produced by refraction of the light from a heavenly body, such as the sun or the stars, as it passes from the regions outside the earth into the earth's atmosphere. All rays of light from heavenly bodies that enter the earth's atmosphere obliquely are bent downwards by refraction. For example, a star does not set or disappear as soon as it passes below the horizon, but continues in view after it has passed for a considerable distance below the horizon. In a similar manner, to an observer on the earth, a star may be seen above the horizon, as if it had just risen, long before it has actually risen, because the ray of light is bent out of its course by refraction.

The duration of twilight long after sunset is due not only to the change resulting from refraction in the direction of the sun's light during its passage through the atmosphere, but also from the fact that, long after the sun has set, its rays pass over the head, and enter the eye by reflection from the higher portions of the earth's atmosphere.

It is, indeed, almost entirely by reflection and not by refraction only, that twilight is due. Young has shown that the length of time required by the sun, after setting, to reach a point about 18° below the horizon when the twilight may be considered as no longer continuing (since stars of the sixth magnitude then become visible directly overhead), varies with the season as well as with the part of the world in which the observer may be situated. At latitude 40° N. on the 1st of March and on the 12th of October, the sun does not reach this point until an hour and a half after its actual setting. At the time of the summer solstice, or the 20th of June, more than two hours are required before the sun, after passing below the horizon, ceases to produce twilight effects. Indeed, in latitudes further north than 50°, at the time of the year when the days are longest, twilight never entirely disappears even at midnight. On the mountains of Peru, however, twilight never lasts more than half an hour.

If a luminous point S be situated below a water surface AE, Fig. 29, its rays will undergo refraction at all points except at B, where they strike perpendicularly against the bounding upper surface. Those which strike obliquely as SC, undergo refraction, continuing their way through the air in the direction of the straight line CC′. Since now the light is passing from water to air the angle of refraction is greater than the angle of incidence, so that a point will soon be found, situated say at D, where the angle of incidence has such a value that the refracted ray will emerge from the water parallel to its surface, represented in the drawing as above the surface so as to be visible. The angle of incidence at which this occurs is called the critical angle. When the angle of incidence slightly exceeds the value of the critical angle, as at H, the light will no longer emerge from the water and be refracted but will undergo what is known as total internal reflection.

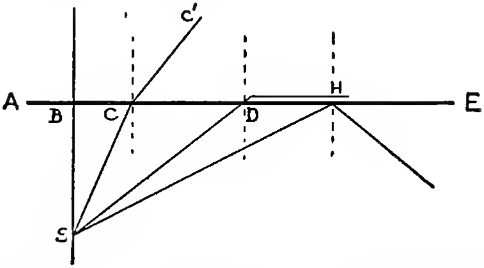


FIG. 29.—CRITICAL ANGLE AND TOTAL INTERNAL REFLECTION.

There is an interesting experiment in total internal reflection that I would advise you to try as it is quite simple and yet very beautiful.

Partially filling a clear glass tumbler with filtered water, rest a spoon in it; then, if you hold the tumbler of water above the level of your eye, the upper surface of the water will be seen to shine like a brilliant mirror, while the image of a portion of the spoon will be seen as reflected from it.

If, while standing near an aquarium, you place your eye in various positions outside, below the level of its water you will at last find a position at which its upper surface, acting as a mirror, will give you by total internal reflection some very beautiful effects of images inside the aquarium.

CHAPTER VII

LENSES

Just as there are variously shaped opaque bodies with convex and concave surfaces, capable of causing pencils of light after reflection to collect at places called foci, so there are variously shaped transparent bodies that are likewise capable of causing rays of light passing through them to collect at similar foci. Such transparent bodies form what are called lenses.

The name lens has been given to these bodies by reason of their resemblance to the flat, rounded seeds known as lentils, found in certain vegetable pods, and at one time commonly employed for food. Lentils are not so much employed now, so that it is possible you have never seen them. If this is so, I can only say that the shape of a lentil resembles that of the ordinary burning glass shown at AB, Fig. 30, which I am sure you have all seen. This particular lens is called a burning glass because it brings

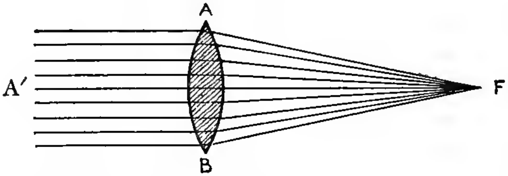


Fig. 30.—Convex Lens Employed in Burning Glass.

a beam of light A′ to a focus F, which, besides being a focus of light rays, is also a focus of heat rays.

As we have seen, mirrors can be divided into two classes: convex and concave mirrors. In a similar manner, lenses are divided into two classes called converging and diverging lenses, according to whether they cause the rays of light passing through them to converge towards, and thus collect at a single point, or cause them to diverge, or pass from a single point.

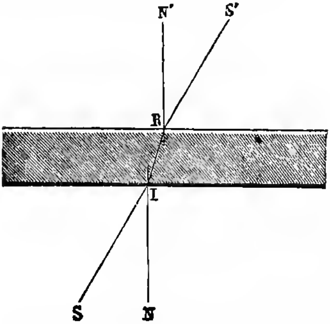


Fig. 31.—Passage of Light Through Plate of Glass.

When a ray of light is caused to pass through a plate of glass the opposite surfaces of which are parallel, as represented in Fig. 31, the ray undergoes a change in its direction, or is refracted, both on entering and on leaving the plate. If, for example, a ray of light falls on the plate in the direction S′R, it is bent in the direction RI on entering the plate as well as in the direction IS on leaving it, and passes out of the plate parallel to its original direction. It does not, however, continue in the same straight line it had when it fell on the upper surface of the plate; for if the straight line S′R be prolonged it will be seen that the emerged ray IS has been turned out of its course.

It is for the above reason that when an object is viewed obliquely through a glass plate bounded by parallel faces, it is seen out of its true position. If, for example, a luminous point is viewed by an eye placed above the glass plate the rays of light, when they finally enter the eye of an observer, appear to come not from its true position, but from a position much nearer the glass. If, therefore, an object be situated on the other side of the glass screen, and is viewed obliquely by an eye, it will be seen out of its true position.

If now instead of employing a plate of glass bounded by parallel sides, a piece of glass in the shape of a prism ABC, Fig. 32, is used, and a luminous point L is placed as shown on one side of the prism, a ray of light LD, falling on the face AB, at D, undergoes refraction, both on passing through the prism at D and again on entering the air and taking the course EL′. This ray of light after passing through the prism, cuts the line XX, corresponding to the base AC, of the prism at the point L′.

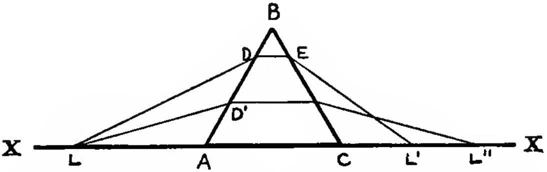


Fig. 32.—Refraction of Light at Surfaces of Prism.

If, however, a second ray of light LD′, falls on the face of the prism AB, at some other point as D′, after passing through the prism, it would cut the line XX, not at the point L′, but at some other point, such as L″, nor would there be any other point than D at which a ray of light from the luminous point L, after passing through the prism would meet at the same point L′ on the other side of the prism.

If, however, the piece of glass ABC, Fig. 33, instead of having a single inclined face AB, is provided with three differently inclined faces as shown, the inclination of these faces might be so arranged that the rays of light LD, LD′, and LD″ might, after passage through the irregularly shaped piece of glass, all meet at a single point or focus L′, on the other side of the glass.

But it would be only the rays that fall on the prism at D″, D′, and D″, that would collect at L′. Those striking at any other portions of the surface between A and B would cut XX′ at some other point.

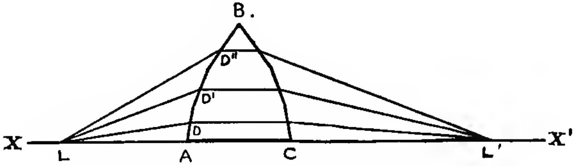


Fig. 33.—The Principle of the Lens.

Now I think you should have no difficulty in seeing that if the opposite faces of ABC, instead of being flat or plane, were curved, or in other words, constantly changed their directions as curved surfaces, it should be possible to cause all the rays of light diverging from a point placed in front of such a surface to come to a single point or focus on the other side. And this would produce what is known as a lens. For it would be only necessary to place a second such surface with its base AC resting on a similar surface as shown in Fig. 34 to have a piece of glass that possesses the power of causing all rays of light diverging from a point L on one side to meet or collect at a point L′ on the other side.

I am now, therefore, able to tell you how a lens is made. It consists of a medium formed of glass, or some other transparent substance denser than air, bounded on its opposite faces either by curved surfaces, or by a curved and a plane surface, that like convex and concave mirrors, possesses the power of causing the rays of light that pass through it to collect at points called foci.

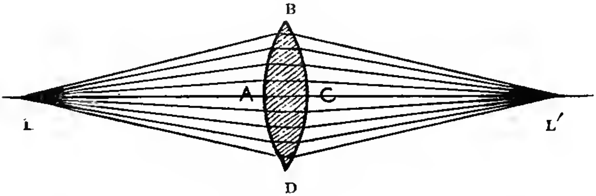
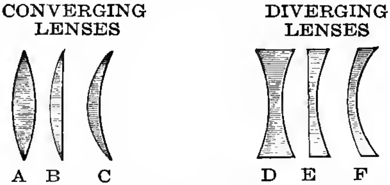


Fig. 34.—Foci of Lens.

As I have already told you, lenses can be divided into converging and diverging lenses. Converging lenses can be divided further into three classes as represented in Fig. 35. I would advise you to memorize the names of these three classes of lenses. That shown at A is called a double convex lens because its opposite faces are convex in shape. That at B is called a plano-convex lens because its opposite faces are respectively convex and plane. That shown at C is called a concavo-convex lens because its opposite faces are respectively convex and concave. This lens is sometimes called a meniscus, a name given to it because of its moon shape. All these classes of converging lenses are sometimes called convex lenses.

If you examine these lenses carefully you will see that they all agree in one respect; they are thicker at the middle than at the edges. This is important since, in all cases, rays of light, when passing through any lenses, are bent from the thinner portions towards the thicker portions. You can see, therefore, that such lenses must converge the light passing through them.

There are also three kinds of diverging lenses; or, as they are sometimes called concave lenses. These are named as follows: That shown at D is called a double concave lens because its two opposite surfaces are concave. It is sometimes merely called a concave lens. That at E is called a plano-concave lens because its opposite faces are respectively plane and concave. And that shown at F is called a convexo-concave lens because its opposite surfaces are respectively convex and concave. This lens is more frequently called a diverging meniscus.



A, Double Convex—B, Plano-Convex—C, Concavo-Convex—D, Double Concave—E, Plano-Concave—F, Diverging Meniscus

FIG. 35.—CONVERGING AND DIVERGING LENSES.

If you examine the different concave lenses you will find that they all agree in that their central portions are thinner than the portions near the edges, and since the rays of light after passing through lenses are always turned from the thinner portions towards the thicker portions, these lenses must necessarily be diverging lenses.

Having now obtained some idea of what is meant by lenses, let us see how a lens brings to a focus the rays of light that pass through it.

Suppose we begin with the commonest kind of light; i. e., daylight or sunlight. The sun is so large a body and is so far off from us that its rays may be regarded as being practically parallel. How then will a beam of sunlight or parallel rays be affected by its passage through either a double convex or a double concave lens. As you will see by an inspection of Fig. 36, at X, when such rays pass through a double convex lens they are all brought to a single focus on the other side of the lens at F. Since the rays actually meet at this point the principal focus of a double convex lens is a real focus.

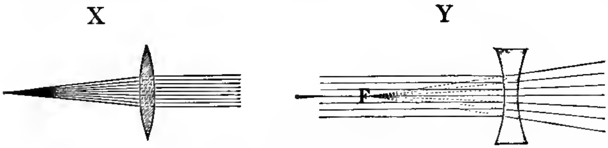


FIG. 36.—FOCUS OF PARALLEL RAYS OF CONVEX AND CONCAVE LENSES.

If, however, a beam of sunlight falls on a double concave lens as at Y, in the same figure, the rays of light, after emerging, diverge as though they came from a focus F on the same side of the lens as that on which the parallel rays fell. This is also called the principal focus of the concave lens. But since these rays of light only appear to meet at this focus, it is called a virtual focus.

You can readily see from the above figures that the double convex lens as shown at X, has acted as a converging lens, since it has bent all the rays of light that have passed through it, so as to cause them to converge or be brought together into a single focus at F.

Not so, however, with the parallel rays of light that have passed through the double concave lens shown in the same figure at Y, for here, diverging, they appear to come from the virtual focus at F.

But convex lenses possess other foci. If, as at X, Fig. 37, a luminous point, C, is placed in front of a double convex lens, at any point greater than twice the principal focus, then after their passage through the lens the rays will be converged or brought to a real focus on the other side of the lens at C′, nearer to the lens than at C, at some point between the principal focus and twice the principal focus. These points C and C′ are called conjoined or conjugate foci because they may replace each other; for, if the luminous point be placed at C′ its focus will be at C. These two foci are called respectively the longer and the shorter conjugate focus.

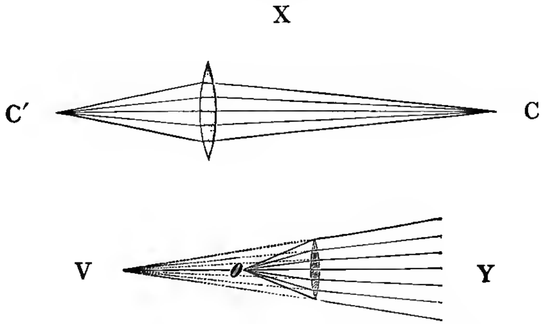


Fig. 37.—Some Other Foci of Convex Lenses.

When the luminous point is placed at O as at Y, Fig. 37

at a point nearer to the lens than its principal focus, then although the rays are converged yet they are not sufficiently converged to meet in a focus at the other side of the lens, but after passing through the lens would appear to come from a focus V, on the same side of the lens called a virtual focus.

As to the effects produced by lenses in the formation of images, we shall understand them better when we discuss some of the simple pieces of optical apparatus. It will suffice here to say that when an object placed quite near a double-convex lens is examined by the eye placed on the opposite side of the lens as shown in Fig. 38, the lens is employed in a very common manner as a magnifying lens, and produces, as shown, an erect and largely magnified image of the object that is being examined.

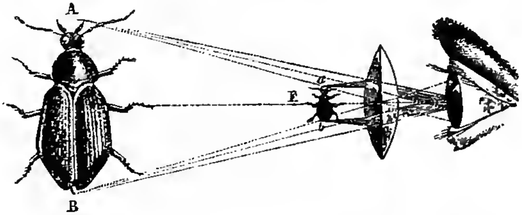


Fig. 38.—Use of Convex Lens as a Magnifier.

If, however, an object is examined in a somewhat similar way through a concave lens, an erect and greatly diminished image of the object will be seen.

There are other images, formed at the longer and shorter conjugate foci of the convex lenses, that are employed in optical apparatus. If, for example, as in Fig. 39, a flower is placed at the longer conjugate foci of a double convex lens, an inverted and decreased image will be seen at the focus, and, since it is a real image, it could be received on a screen instead of on the eye of an observer. Indeed, if a highly illumined object were placed at the shorter conjugate focus of a double convex lens, an inverted and greatly magnified image would be thrown on a screen placed at its longer conjugate foci. As we shall see in a subsequent chapter, this is practically the manner in which the magic lantern operates. For it is only necessary to place a highly illumined inverted picture at the shorter conjugate focus of a double convex lens and receive on a screen a highly magnified image which would now appear in its correct position.

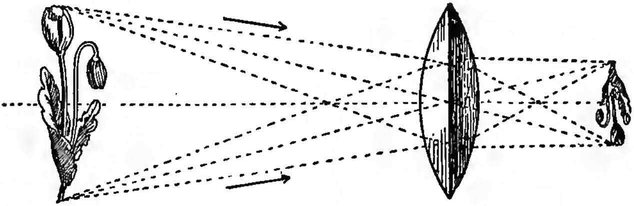


FIG. 39.—FORMATION OF IMAGE BY CONVEX LENS.

Later you will see how highly important the images at the longer and shorter conjugate foci of converging lenses are, as well as the manner in which they are used in such well-known pieces of optical apparatus as the camera obscura, the photographic camera, the compound microscope, the telescope, etc.

CHAPTER VIII

THE MICROSCOPE

THERE are various instruments, consisting either of mirrors or lenses, or of combinations of mirrors and lenses, known as optical instruments, some of which are capable of producing extremely wonderful results.

One of the most important of these is the microscope. As its name indicates, the microscope is a device suitable for the examination of objects that are too small to be seen by the unaided eye.

There are two kinds of microscopes; i. e., the simple microscope and the compound microscope. The simple microscope consists essentially of a single converging lens; the compound microscope consists of two converging lenses.

In the simple microscope, the object to be magnified is placed between the eye and a convex lens, nearer to the lens than its principal focus, as represented in the last chapter in Fig. 38. As the rays of light pass through the lens, they are converged and, entering the eye of the observer, appear to come from a greatly enlarged image of the object that is being examined.

But, while the simple microscope consists essentially of a single converging lens it is generally provided with several additional parts that are necessary to permit the instrument to be easily operated. In the first place, a suitable support or stand must be provided for holding the object. If the magnification is great, and the object is small, it would be too awkward to attempt to hold the object in the hand while magnifying it. Moreover, such a method would prevent the object from receiving on all sides the light necessary to permit it to be greatly magnified. Then, too, the object is often so small it can not be held in the hand. With larger objects, such as watches, plates of metal that are being engraved, or similar articles, this objection is not so serious.

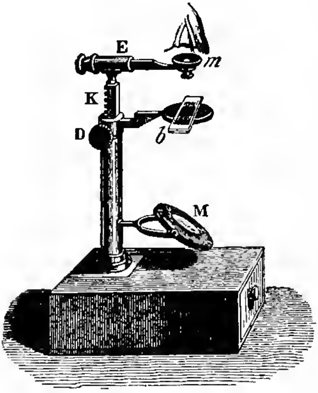


FIG. 40.—SIMPLE MICROSCOPE.

In the form of simple microscope represented in Fig. 40, the object to be examined in this case (a very minute one) is placed between two glass plates in what is called a glass slide, and supported on a stage *b*. No attempt is made to move the object itself towards or from the magnifying lens, but the lens itself, mounted in a brass tube, K, is arranged so that it can readily be moved towards or from the object, by turning the brass screw D, provided with a milled edge.

An important part of a simple microscope consists of means for properly illumining the object. In any optical instrument in which the image of an object is greatly magnified, the illumination of the image is necessarily greatly decreased. Unless, therefore, the object is strongly illumined, its image will receive so little light, that its details cannot be distinctly seen.

The means for properly illumining the objects that are to be examined by a microscope is a very important part of the apparatus. An abundance of light thrown on the object, is especially necessary where the amount of magnification is large.

It is a virtual focus of the lens that is employed, when the lens is used as a magnifying glass. Now there are a number of different virtual foci for every convex lens. Indeed, you would have no trouble in proving this, for you would find, by moving the lens to-or-from the object, that its magnified image can be seen in a number of different positions in some of which it appears much larger than in others. It would not be long, however, before you discovered that there is only one of these positions at which you can see the image distinctly. In other words, there is a certain distance, at which the object must be held from the eye, in order that its minute structure shall be distinctly seen. By moving the magnifying lens towards and from the object, there is obtained the particular distance of the object from the lens that produces the most distinct vision in the eye of an observer. This is known as focusing, or adjusting the lens. Since the eyes of one person differ from those of another person it is generally found necessary for each observer to focus the lens.

There are a number of occupations in which the workmen are obliged to use a magnifying glass. Where the object to be examined is so fairly large that it can easily be held in the hand, it is customary to place the magnifying lens in a cylindrical tube that the workman holds against his eye by the contraction of the surrounding muscles. You have probably often seen a watchmaker at work holding a magnifying glass mounted in a small brass tube firmly in place before one of his eyes. Engravers, jewellers, and others, who work on similar objects that can be supported on a stand, employ magnifying glasses that are held in a similar manner.

The magnifying power of a simple microscope depends on two quantities, one of which is fixed and the other is capable of being varied. The fixed quantity, which varies with different people, is called the limit of distinct vision, or the distance an object must be situated from the eye in order to ensure the most distinct vision. For most people, the limit of distinct vision is about ten inches. The quantity that is capable of being varied is the length of the principal focus of the magnifying lens, or the distance on the other side of the lens at which a beam of sunlight is brought to a focus. The magnifying power of a lens is obtained by dividing the limit of distinct vision by the length of the principal focus, so you can easily calculate the magnifying power in the case of any particular lens.

Magnifying lenses can be purchased at almost any opticians for a small price. I would advise you to get one and make experiments with it. If you hold it in a beam of sunlight, in front of a sheet of paper, you can get a bright spot of light just as you would with the lens as a burning glass. The distance between the lens and the paper is the principal focus of the lens. Now let us suppose that this distance is equal to one inch. Since your limit of distinct vision is say ten inches, and the magnifying power of the lens is equal to the limit of distinct vision divided by the length of its principal focus, and you have just proved this to be one inch, then the magnifying power of that particular lens is ten divided by one; that is, ten. This means that an object when examined by such a lens looks ten times longer and ten times broader than it actually is.

It is evident that if you wish to obtain a high magnifying power you must get a lens of a short focal length; for, the shorter the focus is, the greater will be the magnifying power. Suppose, for example, you obtain a lens whose focal length is half an inch, then its magnifying power would be twice as great as if its focal length were one inch; for ten divided by one-half equals twenty. In the same way, if the focal length of a magnifying lens be one-tenth of an inch, then its magnifying power would be ten divided by one-tenth or 100.

Up to a certain limit it is not difficult to obtain convex lenses with comparatively small focal lengths. But as soon as this limit is passed, it becomes exceedingly difficult to get satisfactory lenses of this character; for, when an attempt is made to get a lens with a fairly short focal length, certain imperfections are almost sure to be introduced into the lens. These will be described more fully in a subsequent chapter. These imperfections or diseases are certain troubles or difficulties that result in the failure of lenses correctly to reproduce, in their highly magnified images, either the correct outlines or the correct colours of the objects they have magnified. Consequently, while one may obtain lenses of short focal length, and therefore of great magnifying powers, yet these lenses may produce images with their outlines so contorted, and their colours so false that they are of very little use as magnifying lenses.

Another difficulty is found in the fact that lenses with very short foci must be comparatively small, and consequently will have a small width. This will necessarily limit the amount of light that can pass through the lens into the eye of the observer, and this will stand in the way of great magnification, unless the amount of light thrown on the object to be examined is quite large.

The method generally employed for obtaining lenses of short focal length, without too greatly decreasing their width, is to employ more than a single lens. If, for example, two separate lenses are placed together as represented in Fig. 41, and mounted as shown, the focal length of the combination will be much smaller than that of either of the lenses separately. Moreover, as we shall afterwards see, by the proper use of such a combination of lenses, known generally as an eye piece, images are obtained in which false outlines and false colours are to a great extent avoided.

FIG. 41.—MAGNIFYING LENSES OF SHORT FOCAL LENGTHS.

In the above figure there is employed a combination of two plano-convex lenses placed with their flat sides towards the object to be examined.

Sometimes, in order to decrease still further the amount of false colouration and false outline, a device called a diaphragm is used. This consists of a flat plate of brass, or other metal, covered with some dull black material like lampblack mixed with turpentine, that possesses little or no power of either reflecting or diffusing light. It is the edges of lenses that cause the greatest amount of false colouration, and false outlines of objects. Therefore, by placing a diaphragm with its central opening immediately over the centre of a lens, the light is prevented from passing through the edges. In this way the images formed are comparatively free from false colouration or from false outline.

There are two ways of expressing the magnifying power of a lens. One, called the linear magnifying power, is to give it in terms of the width or breadth of the object. A lens whose focal length is one-tenth of an inch, as we have explained above, would have a magnifying power of 100; that is, such a lens would make an object appear 100 times longer as well as 100 times broader. Now sometimes the magnifying power of such a lens is given in what is called its superficial magnifying power, where both the length and breadth of the object are considered, the magnifying power being expressed as the increase in the area. Since areas are obtained by multiplying the length by the breadth, the superficial magnifying power of a lens is as the square of its linear magnifying power, a lens that has a linear magnifying power of 100 would have a superficial magnifying power of 100 multiplied by 100, or 10,000.

A simple way of measuring the magnifying power of a lens is shown in Fig. 42. Here a plane reflector, consisting of a piece of glass provided with a hole in its centre, is placed as shown in front of the eye-piece of a microscope inclined at an angle of forty-five degrees. Another reflector, in the shape of a prism, is placed parallel to the microscope at a distance of an inch or two, so that the eye, looking down on the first mirror, is able to see the reflected light that comes from a graduated scale placed at A, eight or ten inches below the prism. In making an observation, a similar scale is placed in the microscope instead of the object to be magnified. The observer, whose eye is placed as shown, is able to see both scales simultaneously, and can, therefore, directly determine the magnifying power by noting how many times the magnified scale is larger than the unmagnified scale.

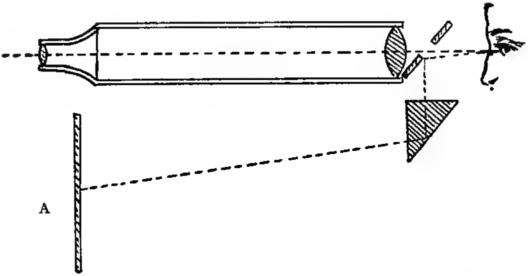


FIG. 42.—MEASUREMENT OF MAGNIFYING POWER.

In the compound microscope there are two image-forming lenses, each of which magnifies the object that is being examined. The first produces a magnified image of the object, and the second a magnified image of the magnified image of the object. In the compound microscope, therefore, the amount of magnification is much greater than in the simple microscope.

The two lenses employed in the compound microscope are called respectively the object lens and the eye lens. The object lens O is the lens that lies next to the object that is being examined. It is sometimes called the objective. The eye lens O′ is the lens that lies nearest the eye of the observer.

Although, in the above description of the compound microscope, I speak of both the object lens and the eye lens as being single lenses, yet, in point of fact, each generally consists of a combination of several lenses. Since, however, these combinations act as single lenses, it is simpler, in giving the general explanation of the instrument, to regard them as single lenses only.

Now in the compound microscope the object to be examined is placed in front of the object glass at a shorter conjugate focus in such a position that a greatly magnified and inverted image of the object is formed at the longer conjugate focus, and this already magnified image, being examined through the eye lens, is still more greatly magnified. In the compound microscope, therefore, the magnification of the object is very much greater than in the simple microscope.

The compound microscope is generally provided with a variety of object glasses and eye-pieces and with devices for focusing and for illumining the object. This makes the compound microscope, when of a high grade, an exceedingly expensive piece of optical apparatus.

A form of compound microscope is represented in Fig. 43. The object lens, or, as it is generally called, the objective, is seen at O, the eye-lens, or, as it is generally called, the eye-piece at O′.

The object *ab* to be examined is placed in front of the object glass at a shorter conjugate focus. A highly magnified inverted image of this object is formed at the longer conjugate focus of the lens at a′ b′. The distance between the objective and the eye-piece is such that the image falls at such a distance from the objective O, as to permit the eye to view it as a highly magnified image at its limit of distinct vision.

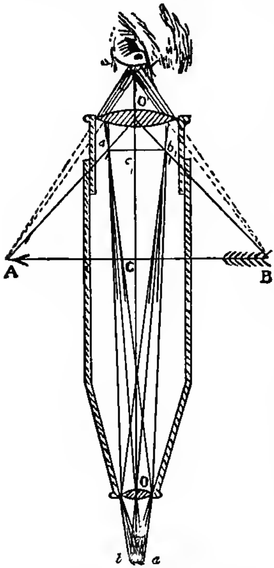


Fig. 43.—Compound Microscope.

In the compound microscope, both the objective and the eye-piece consist of a number of lenses so arranged as to act as a single lens. By means of these combinations of lenses a greatly magnified image of the object is seen at AB, both in its true or natural colours, and free from false outlines.

The ocular, or eye-piece, as well as the compound objective, are placed inside a series of brass tubes DD′, I and H, Fig. 44. The eye-piece at O, is placed in the tube H, and the object glass *o*, in the lower part of the tube DD′. By means of suitable mechanism the tube I can be moved to-and-fro with gentle friction in the tube DD′, and this tube can also, in its turn, be moved in the larger tube fixed in the ring E. This latter ring is also so fixed to the piece BB, that by turning a fine screw T, by means of its milled head, it can be raised or lowered very gradually. This forms what is called the fine adjustment. Besides this, the entire body of the microscope can

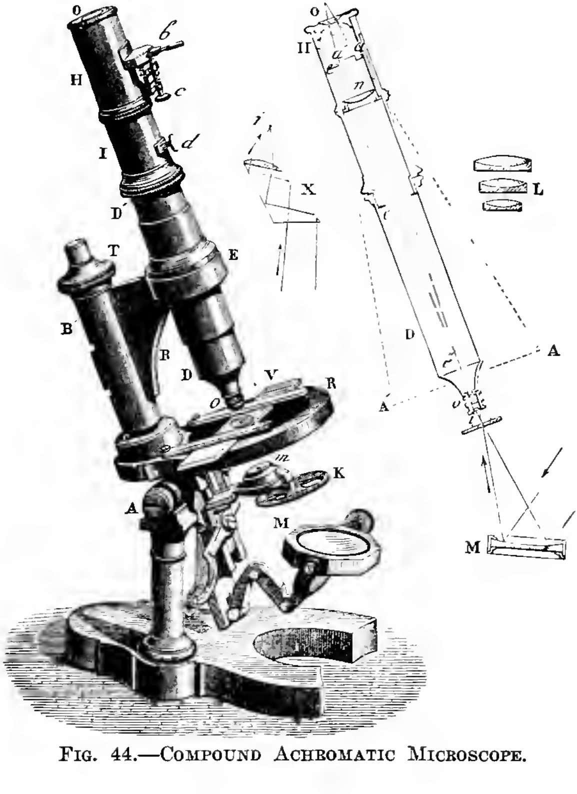


FIG. 44.—COMPOUND ACHROMATIC MICROSCOPE.

be raised or lowered by suitable means, thus forming what is known as the coarse adjustment.

The object to be examined is placed between two glass plates V, on a stage R, provided with a large central aperture or opening, through which light can be thrown upwards on the object from a large concave mirror M. This mirror is moved on an ingeniously arranged jointed support, so that it can be placed in any position that may be necessary to throw the diffused daylight of the room from a plane mirror on one side, or the light of a gas burner, or lamp, from a concave mirror on the opposite side. A convex lens, not shown in the figure, is sometimes arranged to throw a strong pencil of light on the object from a lamp.

A diaphragm K, provided with openings of different sizes, placed between the reflector and the stage, can be so turned as to place any of these openings directly under the stage so that the amount of light thrown upwards on the object can be varied at pleasure.

On the right-hand side of Fig. 44 you can see the manner in which a pencil of light is thrown upwards from the reflecting mirror M, and entering the objective passes through the different lenses of a compound microscope. As here shown, the object glass consists of three small compound lenses, each of which is made of two different kinds of glass, the use of which in preventing false colouration will be afterwards explained.

In a high-class compound microscope, the focal lengths of some of the object glasses are so short that, in order to bring the objects sufficiently near the objective, it is necessary to cause them to cling to the objective by moistening them with a drop of liquid. Such lenses are called immersion lenses, and constitute no inconsiderable part of the cost of the apparatus.

CHAPTER IX

THE TELESCOPE

As its name indicates, the telescope is an optical instrument suitable for the observation of objects at a distance. The word is of Greek origin.

Telescopes can be divided, according to the purposes for which they are intended, into astronomical telescopes and terrestrial telescopes.

Fig. 45.—Astronomical Telescope.

The general appearance of an astronomical telescope is shown in Fig. 45. As you will see, this instrument is large at one end and small at the other. The large end O, is pointed towards the star or other distant body to be examined, while the eye of the observer is placed at the small end O′. A convex lens is placed at each of these ends, the one at the larger being called the object glass, because it is pointed towards the object, and the smaller one, the eye-piece, because it is placed near the eye. A smaller telescope *a,* placed on the top of the instrument, is known as the finder. Its purpose will be explained shortly.

The arrangement of the lenses in an astronomical telescope will be understood from an examination of Fig. 46.

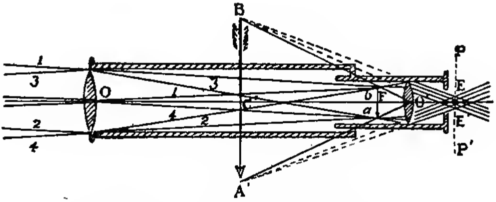


Fig. 46.—Lenses in Astronomical Telescope.

The object glass O, in some instruments, is more than twelve inches in diameter, and is always of a much greater local length than the eye-piece O′.

Since the telescope is always employed for the examination of a distant object such as the sun, a fixed star, or something on the landscape, this object is always situated at a longer conjugate focus of the object lens. An inverted image of this object is, therefore, always formed at a shorter conjugate focus. And since the image of an object at the longer conjugate focus of a converging lens is always smaller than the object, the first thing a telescope does is to make the image of the distant object appear smaller than it would if looked at directly. This, however, strongly illumines the image, and, therefore, permits it to be highly magnified, when examined by the eye-piece or eye-lens O′.

So far as the two lenses of a telescope are concerned, the object glass and the eye-piece are exactly like the object glass and the eye-piece of a microscope, with, however, this difference: in the telescope the object examined is necessarily so far from the object lens that it is situated at a longer conjugate focus, and its image is, therefore, smaller than the object; while in the microscope the object is so near to the object glass that it is always situated at a shorter conjugate focus. Its image is, therefore, magnified, and, as a rule, largely magnified. In both cases these images are subsequently magnified by the eye-piece through which they are seen.

I think you will have no difficulty in understanding that, since the first action of a telescope is to make the object examined appear smaller than it would to the naked eye, the image finally seen through the eye-piece is magnified to a much smaller extent than in the microscope.

You may ask, and quite naturally, why is the object glass of a telescope so large. The answer to this question would be the wolf's answer to little Red Riding Hood:

"To see the better, my dear."

The object glass of the telescope is enlarged in order that it may see distant objects better. By the use of a large object glass, one is able distinctly to see clearly objects so far off that the amount of light that would enter the eye, when looking directly at them, would be too small to permit their being seen at all, much less to be magnified. Although a much smaller image of the distant object is thus formed than would be if examined directly by the eye, yet the use of a large object glass produces an image so strongly illumined that it can be magnified, to any reasonable extent, without becoming too faint to be distinctly seen.

In order to give you some idea of the extent to which the object glass of a telescope is sometimes able to increase the amount of light that is swept into the eye, I will mention the case of a large telescope constructed as early as February, 1845, for the English astronomer, Lord Rosse. The objective of this telescope, as was commonly the case with large astronomical telescopes at this time, instead of consisting of a glass lens, was a huge concave mirror, some six feet in diameter. Since the amount of light that falls on a surface is proportional to the square of its diameter, and since the pupil of the human eye, the name given to that portion of the eye which permits the light from the outside to enter it, is only one-tenth of an inch in diameter, then the reflecting mirror employed in this huge telescope, which was six feet, or seventy-two inches, in diameter, was 720 times wider than the pupil of the eye. Squaring this, or multiplying 720 by 720 we have 518,400 times. In other words, the area of Lord Rosse's telescope was roughly 518,400 times greater than the pupil of the eye. Now, since the telescope was arranged so as to bring all this light to a focus, thus permitting it to pass through the pupil of the eye of the observer, you can understand that it was able to collect in this way from a distant object and transmit to the eye for the purposes of visions an amount of light enormously greater than that which the naked or unassisted eye could. Indeed, even supposing that one-half of the light was lost by reflection from the mirror, yet the amount collected would still be more than 250,000 times greater that what the eye alone could collect. Such a telescope, therefore, would possess a marvellous penetrating power, enabling objects to be seen at far greater distances than could the eye itself.

I am anxious that you should understand this matter thoroughly, since this ability to collect light and transmit it to the eye is one of the principal advantages possessed by the telescope. It is true that by the use of a proper eye-piece we can magnify the bright image produced by the object glass so as to make it appear larger than it would appear when examined without a telescope. But this is not the principal function of a telescope. Its function is rather to see "far" and "more distinctly" than it is to see "large."

Generally speaking, a feeling of surprise and disappointment is experienced when one looks for the first time through a powerful astronomical telescope at a distant object, such as the moon. The image is by no means as large as the observer expected. He has likely associated the size of the telescope with the size of some microscope through which he has looked, and expects to see a highly magnified moon, having doubtless argued to himself that if a little microscope can make a tiny object look as big as his head, then how immense must be the magnification of a large body like the moon when seen through so large an instrument as the telescope. He should remember, however, that in the case of very distant stars he is looking at objects that he would be unable to see at all without the aid of the telescope. The telescope, although it usually has a magnifying power of about ten diameters, has swept so great a quantity of light into his eyes that he can see these objects not only distinctly, but also somewhat larger than they would appear had they been directly visible.

An extremely important part of an astronomical telescope is the equatorial mounting. Even with the comparatively small magnifying powers employed on telescopes, the rotation of the earth on its axis would soon result in causing a celestial object to pass out of the field of view, thus making any long continued observations impracticable. In order to avoid this difficulty, a very ingenious mechanism is used.

The arrangements are such that the telescope can be vertically raised or depressed on its second axis and can also be moved at right angles to these directions on the first axis so that it can be made to point at some particular part of the heavens, say to a star. When it is firmly clamped in this position clockwork motion keeps it pointing to this part of the heavens although by the rotation of the earth on its axis the star is apparently moving across the telescope from east to west; for the clockwork moves the telescope just as fast in the opposite direction, and, therefore, keeps it pointed to the same part of the sky.

The terrestrial telescope differs from the astronomical telescope in that it produces erect images. In the astronomical telescope the fact that its images are inverted, or turned upside-down, does not make any great difference, but would of course be objectionable where objects on the earth's surface are to be viewed. It is necessary, therefore, in the terrestrial telescope to re-invert the image, so as to make it appear in its ordinary position. This is usually done by the introduction of two additional lenses at O″ and O″ ′, Fig. 47, between the image *a′ b′*, and the eye lens O′. How these lenses make the inverted image erect can be understood by tracing the path of the rays of light through the lenses.

An eye-piece provided with these additional lenses is known as the terrestrial eye-piece. While it produces an erect image, yet the terrestrial eye-piece possesses the disadvantage of causing a considerable loss of light during its passage through the two additional lenses. It is also objectionable by reason of the increased length it gives the telescope.

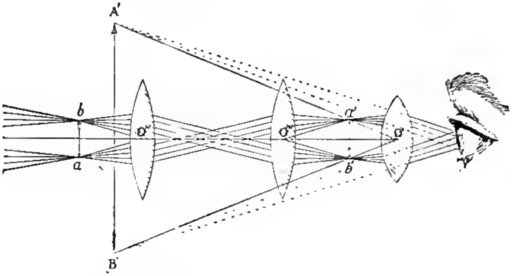


Fig. 47.—Terrestrial Eye-Piece.

It is interesting to note here that in one of the first telescopes ever produced, namely, that invented by Galileo, a concave lens was employed for the eye-piece. This inverted the image produced by the object glass and thus produced an erect image. The construction of the Galilean telescope, and the manner in which it operates to ensure an erect image can be seen from an examination of Fig. 48.

You are probably all familiar with the opera glasses that are used at the opera, theatre, or other crowded places, for viewing people on the stage or in different parts of the house. These glasses consist of two small Galilean telescopes, suitably mounted in two tubes. The object glasses generally consist of combinations of lenses that act as a single convex lens, and of eye-pieces that act practically as a concave lens.

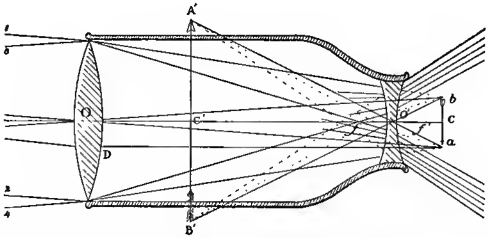
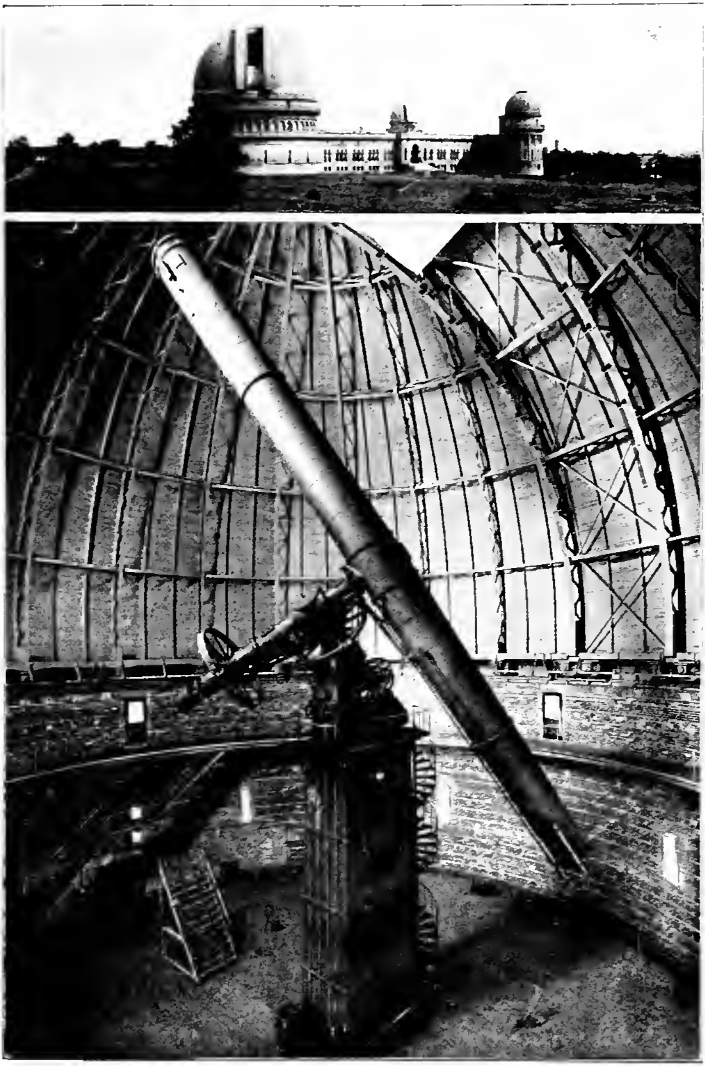


FIG. 48.—CONSTRUCTION OF THE GALILEAN TELESCOPE.

Somewhat similar instruments, mounted like opera glasses, but generally provided with much larger object glasses so as to sweep a greater quantity of light into the eye, are employed by navigators at sea for the purpose of viewing distant objects. These are generally known as marine glasses.

Sometimes the object glass of a telescope, instead of consisting of a convex lens, consists of a reflecting mirror. For this purpose a concave mirror, known as a speculum, is employed. Since a reflector necessarily forms its image on the same side of the object as itself, various methods



A.—Yerkes Observatory, Williams Bay, Wisconsin

B.—The Forty-inch Refractor of the Yerkes Observatory: the Largest in the World

are employed for examining through the eye-piece the image formed by reflection from the mirror. In some forms of reflecting telescopes, a circular opening is cut in the centre of the mirror and a second mirror is placed in front of it in order to throw the image onto the eye-piece. Since this method prevents the best—that is, the central—portion of the reflector from being used, another method is generally employed, such, for example, as that used in Newton's telescope, where the mirror is placed inside a tube with its reflecting surface turned towards the distant object; and the image formed by the mirror is magnified by means of an eye-piece placed at right angles to the reflected rays. The mirror is placed inside a tube with its reflecting surface pointed towards the distant object. The image formed in this mirror is magnified by means of the eye-piece placed at right angles to the reflecting surface, the rays being passed into the eye-piece by a rectangular prism. The general appearance of the Newtonian telescope when mounted in its tube and provided with its eye-piece is shown in Fig. 49.

Owing to the difficulties of making large reflectors of the required shape and of keeping them polished, reflecting telescopes are now but seldom employed, being almost entirely replaced by some form of refracting telescope.

It is also extremely difficult to mount a large reflector so that it can be safely turned on its edge into the vertical or inclined position it must take when pointed towards a star or other heavenly body that is not immediately overhead. Unless great care is taken to stiffen the huge piece of metal or glass that forms the mirror, it will bend slightly. Although this bending is so small that you could by no means detect it with the unaided eye, it is, however, sufficiently great to distort the image formed by reflection from the mirror and render it useless.

Then again another difficulty arises from the necessity for keeping the surface of the speculum polished, so as to make the amount of light lost by reflection as small as possible. This polishing requires great care, since, unless it is done properly, the mirror will lose the true curved surface it must retain in order to form correct images.

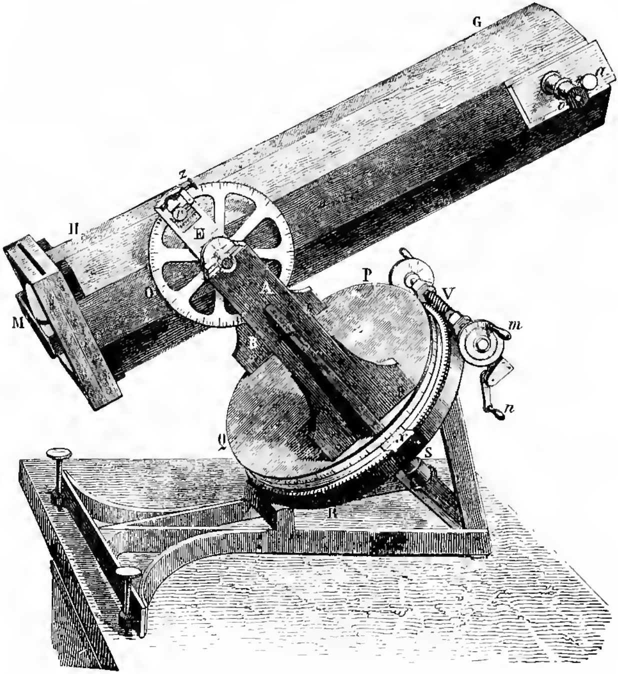


Fig. 49.—Newtonian Telescope.

Moreover, if during the polishing process, a portion of the surface be thoughtlessly touched for a moment by the finger, it will become heated, and will bulge out by local expansion. If, now, the polishing is continued before the entire surface of the mirror cools, a small portion of the swelled surface will be removed, thus leaving a little depression or pit that will of course injure the distinctness of the image. The same difficulty is especially apt to occur during the final grinding of the surface.

Although large lenses are subject to similar objections, yet they are never made of the great size of reflectors, and, therefore, are more rigid.

The magnifying power of a telescope is the enlargement of its image as seen in the telescope as compared with the apparent dimensions of the object as seen by the unassisted eye.

The illuminating power of a telescope is the amount of light the telescope is able to collect from a distant object and transmit to the eye for the purpose of vision as compared to the amount of light the naked eye is able to collect.

It is on the magnifying and illuminating power that the penetrating power of a telescope depends. This penetrating power is the ratio of the distances at which the eye and the telescope would collect, for the purposes of vision, an equal amount of light.

The magnifying power is the "how big" the telescope makes the distant object appear as compared with what the eye could do.

The illuminating power is the "how bright" the telescope makes the distant object appear as compared with what the eye could do.

And the penetrating power is the "how far" a distant object will be and still permit the telescope to examine it as compared with what the naked eye could do.

To the above definitions might be added another known as the visual power of a telescope. This may be defined as the "how well" the telescope will enable one to view a distant object as compared with what the unassisted eye could do.

It may interest you if I tell you something about the invention of the telescope. According to some, the telescope was accidentally invented by two boys while playing with the lenses their father, Zachary Jansen, a maker of spectacles, employed in his business. Jansen lived in Holland and the discovery referred to is said to have taken place during the year 1608, so you see the telescope has been known for a very long time.

It is said that the two Jansen boys had placed the spectacle lenses, with which they were playing, at the proper distances apart and were looking through them at the weathercock on the top of a distant church steeple. They were surprised at discovering two things; first, that the weathercock appeared upside down; and, second, it could be seen much more distinctly through the glasses than with the naked eye. Of course, they called the attention of their father to this curious discovery. Jansen, who was an intelligent man, and well acquainted with the properties of lenses as they were known at that early time, constructed a telescope based on the discovery of his sons.

The story about the Jansen boys is, I believe, generally discredited. It appears there are two other claimants for the honor of the invention; a man named Joseph Andriansz, and a man named Lippershey. Lippershey is generally credited with this invention. He was a spectacle maker, who, in 1608, by arranging two convex glasses in a tube, produced a telescope by which he was able to see objects at a distance.

It sometimes happens, in the history of science, that a great discovery is born so much out of date, or so far in advance of a time when it could be appreciated that, like immature fruit, it drops from the tree that bore it without reaching maturity. Fortunately, this was not true with the first telescope; for, it was made during the lifetime of one of the most celebrated Italian philosophers, the great Galileo Galilei.

Galileo, who happened to be in the town where Lippershey had produced his first telescope, called on the inventor and examined the instrument with great care. Now, Galileo was probably the foremost astronomer of his time. Recognising the great aid that would be given to astronomers in examining the heavens by the use of the curious instrument that Lippershey had shown him, Galileo made a careful study of its construction, and from his knowledge of optics was able to produce an instrument with two lenses that enabled him to obtain a much better view of a distant body, in an erect instead of an inverted position, than in the Lippershey telescope. The instrument Galileo constructed was the Galilean telescope before referred to that employs a convex lens as an object glass, and a concave lens as an eye-piece.

Galileo built his first telescope in 1609. It was not much of an instrument, consisting as it did of two lenses placed at the opposite ends of an organ pipe. But this little instrument, known as Galileo's tube, produced the most astounding effects over all civilised Europe.

Being an astronomer, the first thing Galileo did was to turn his telescope to the heavens. Small and clumsy as it was, its penetrating power was much greater than that of the eye, its illuminating power was vastly greater, and even its magnifying power was fairly good. By its use, therefore, he entered a hitherto unknown world in the heavens. Better still, he not only saw the wonderful marvels the glass revealed to him, but he understood them, was able to spread the knowledge of these things in language so simple that a child could understand it.

You must know that when Galileo was making these wonderful discoveries with the telescope, the knowledge the world had of the solar system, that is, of the sun and the bodies that revolve around the sun and obtain their light and heat from it, was exceedingly vague. The earth was by most regarded as the centre of the solar system. The sun and all the heavenly bodies were believed to revolve around the earth, instead, as of course you know is the case, of the earth revolving around the sun.

By means of his little tube, Galileo succeeded in showing that these views were entirely erroneous; that the sun is the centre of our system; that the earth and the other planets revolve around the sun. This, after considerable opposition, he succeeded in proving to all fair-minded men, although it got him into considerable trouble.

Among other objects to which Galileo turned his telescope was the moon. Instead of the apparently smooth surface the moon presents to the eye, the glass showed that it was even more diversified with mountains and valleys, hills and plains, than is the surface of our earth. He proved that in certain positions, the planet Venus presented crescent shapes like the moon; that the planet Jupiter has a number of moons revolving around it, somewhat resembling the single moon our earth possesses. But the great wonder the Galilean telescope disclosed, was the fact that the stars constituting the hosts of heaven, great as they appear in numbers to the unassisted eye, were marvellously multiplied when examined with the telescope. This was especially true when he turned his telescope to a part of the heavens known as the Milky Way. As you probably know, that is a part of the sky that on a clear night presents a hazy, misty appearance, as though someone has spilled milk over the blue vault of heaven. When examined by Galileo's tube, the milkiness disappeared and thousands upon thousands of stars were seen, so far off as only to produce a hazy uncertain light to the naked eye, but seen as separate stars through the telescope. There were, however, here and there in other portions of the sky, dim misty masses known to astronomers as nebulæ.

Galileo now determined to build a larger telescope which by collecting a greater quantity of light would enable him to examine the distant nebulæ. This examination was one of the first uses to which he put his new and enlarged instrument. Its penetrating power was sufficient to reveal, instead of the misty, hazy, nebulous light, thousands upon thousands of stars. In still more remote regions there were other nebulous masses that his telescope was unable to resolve.

CHAPTER X

THE CAMERA OBSCURA, THE PHOTOGRAPHIC CAMERA, AND THE MAGIC LANTERN

WHILE describing the formation of images by the passage of light into a dark room through a small opening in a shutter, I remarked that, when you had studied the principles of lenses, you could understand how much better and more distinctly images could be formed with a lens than an aperture. If the dark room is of sufficient size to contain a chair and a table at which one can sit, and if a lens, provided with a mirror for changing the direction of the rays of light, is placed in a suitable opening, the image may be received on the surface of a sheet of paper placed on the table, so that a person, sitting on the chair, can readily sketch or draw the image.

Since the lens employed is a converging lens, and the illumined object is situated at its longer conjugate focus, the image on the paper will be inverted and smaller than the object. Its illumination, however, will be brighter than it would be if the object were viewed directly by the eye.

Of course, you will understand that, besides a lens, it is necessary to employ a mirror, or some other device, in order to change the direction of the rays of light coming from the distant object, so as to cause them to pass through the image-forming lens. It is not difficult, however, to place an inclined mirror so that this may be done.

It is possible, however, by employing a piece of glass, shaped as shown in Fig. 50, to combine both a mirror and lens in the same device; for, as shown, the convex surface of the image-forming device acts as a converging lens, while the rays of light, on striking the back of the lens, undergo internal reflection, and thus pass through the lower portion of the lens, and emerging, produce an image on a sheet of paper below.

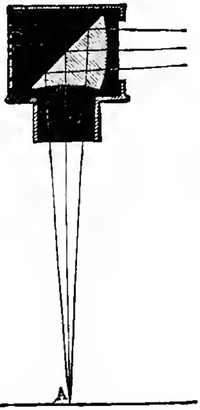


FIG. 50.—COMBINED IMAGE FORMING LENS AND MIRROR.

Of course, the room in which the camera obscura is placed may be large enough to permit a number of people to examine the picture at the same time. I remember a camera obscura that was erected at Asbury Park, New Jersey, a well-known bathing resort on the Atlantic. At the bathing hour, it was beautiful to examine in the dark room the lifelike pictures received on the smooth, whitened surface of a table placed in the centre of the room. Not only could the movements of the breakers be seen, as coming in from the ocean they curled over and broke and finally dashed against the beach, but the images of thousands of bathers, in all kinds of postures, made an animated and at the same time exceedingly interesting picture.

So much pleasure can be obtained from a camera obscura that I would earnestly advise you to make one. If you do this, try to locate it as near as possible to some place where at times there are apt to be crowds of people, since the pictures thus obtained will have a lifelike air about them that will produce very satisfactory results.

There is another kind of camera obscura (or as the phrase means, darkened chamber), in which pictures of distant objects are received, and in which such pictures may be copied, not by drawing with lead pencils, etc., as represented in the above figure, but by photography. In this case a sensitive paper prepared in a certain way, and covered with various salts that possess the power of being darkened when light falls on their surface, can be used to make the sunlight do the drawing, in a far more accurate manner than could the most skilled artist. Suppose you are in the darkened chamber of a camera obscura. Instead of permitting the image of distant objects to fall on the table on a sheet of common paper, let it fall on the surface of a sheet of photographic paper. Then, of course, you would be able to obtain a photograph of the image received on the table; for that image consists of various patches of light of varying degrees of intensity. Where the greater quantity of light falls, there is produced a more decided blackening of the paper. The dark portions are hardly affected at all, while the portions of intermediate brilliancy are darkened to different degress. Consequently, there will be produced on the paper a series of light and dark patches, arranged in the reverse order of the light and dark portions of the objects; for all the light spots have darkened the paper, while the dark spots have left it unaffected, and, therefore, white. Such a picture is called a photographic negative, because the lights and shadows are the reverse of what they are in nature.

If you use a camera obscura as a photographic camera, in which the picture is printed "while you wait," the walls, ceiling and floor of the room must be blackened, so as not to reflect or diffuse light on the picture. Indeed, this should always be done in order to obtain the most satisfactory results in a camera obscura. Moreover, you must afterwards subject the sheet of photographic paper to a process known as fixing, the nature of which will be explained in a subsequent chapter on photography. Unless the picture is "fixed" the entire surface of the paper would be blackened when it is taken out of the darkened room and exposed to the light.

But a camera obscura would be too awkward for use as a photographic camera. It is more convenient to carry the photographic camera to the object than to permanently fix it in one place, when of course you could only take photographs of outside objects at that place. Nor is it necessary to make the darkened room large enough to hold a table for the support of the photographic plate, or big enough to permit people to enter the room, while the picture is being taken. On the contrary, the photographic camera is generally so small that it can be packed in an exceedingly limited space.

The photographic camera is a ridiculously simple piece of optical apparatus when you once thoroughly understand its construction. It consists merely of a light-tight box with a lens so placed in an opening in one of its sides directly opposite a place provided for the reception of a photographic plate, as to have the image fall sharply on its surface. There are a number of devices provided in order so to adjust the image-forming lenses that a sharply focused image shall fall directly on the sensitive surface of the plate. Moreover, means must be provided for examining the image, before the sensitive plate is introduced into the camera, in order to see that the focusing has been properly done. Then, too, there must be means for the introduction into and the subsequent removal of the photographic plate from the camera, so that no light can fall on its surface except what it receives from the image-forming lens.

Fig. 51 represents a photographic camera mounted on the usual tripod. The apparatus consists of a darkened box or chamber C, provided at one end with a double convex lens A, and at the other end with a readily removable frame or box B, placed immediately opposite the lens. This frame is provided with a plate of ground glass E, intended to receive the image of the lens A, when sharply focused on it by a focusing screw D, placed as shown.

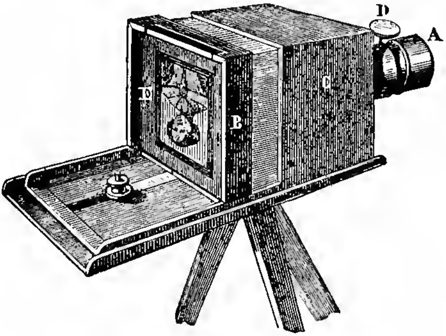


FIG. 51.—PHOTOGRAPHIC CAMERA WITH GROUND GLASS PLATE IN POSITION.

The inside of the box of the photographic camera must be made absolutely light-tight. The only light that is permitted to enter is that which passes through the image-forming lens A, for the purpose of forming the image. Should only a small quantity of light enter from any other part of the box, it will act on the photographic plate and completely ruin the picture.

It will be observed that in all cases the objects that are being photographed are situated outside the camera at the longer conjugate focus of the image-forming lens, so that the image is always much smaller than the object and is received in an inverted position on the photographic plate.

In order to see the image clearly, while focusing the instrument, it is necessary to cover the back of the box with a dark cloth. You who have probably often seen a photographer focussing the image in a photographic camera, will remember how he stood facing the ground glass screen, with a dark cloth so thrown over his shoulders and head as to prevent any light from falling on it from the back of the ground glass screen. In this position he is able clearly to see the inverted image formed on the plate of ground glass, and can so adjust or focus the lens A by moving it towards or from the object, as to produce a sharply defined inverted image.

The image being sharply focused on the ground glass plate, it is then necessary to introduce into the camera a sensitive photographic plate. This is done by means of a device called a plate-holder, consisting of a light wooden frame, generally containing two sensitive photographic plates, one at the back and one in the front, covered by a light-tight sliding plate of thin hardened black rubber. The plate-holder is slipped into the camera in such a manner that, when the hard rubber slide is drawn up, the sensitised surface of the plate thus uncovered occupies exactly the same position the ground glass plate did. The image of the lens, being then received on the sensitised plate, produces a photographic picture by means of chemical changes that will be explained in the subsequent chapter on photography.

As soon as the plate has been properly exposed, a cap is slipped over the image-forming lens, so as to prevent the rays of light from continuing to enter the camera, and the hard rubber plate is slid down on the plate holder while it is still in the camera, thus permitting it to be safely removed.

I need not tell you that you must be careful to remember which side of the plate-holder you have already exposed. Should you forget and expose the same plate twice, when you come to develop the plates, you will learn two things, neither of which is calculated to please you. One of these is that of the two plates in the plate-holder, one contains no photographic picture whatever, while the other plate contains two different pictures, each of which can be distinctly seen, though each mars the other. To make this the more provoking, it too frequently happens that these double pictures are the best exposures that you have made; like the famous fish, the biggest and best, you would have caught had it not unfortunately escaped from your hook just as you had almost landed it.

Photographic plates are now made so sensitive as to produce excellent pictures by an almost instantaneous exposure. It would, therefore, be impossible properly to uncover the photographic lens by slipping a cap off its face and then covering it again by replacing the cap. You could not do this quickly enough. This would result in an overexposure and therefore an unsatisfactory negative. All first-class cameras are now provided with a device operated by compressed air, that, on the pressing of a small India rubber ball filled with air, automatically opens and closes the diaphragm or shutter placed in front of the lens in a very small fraction of a second. The click you hear on exposing a Kodak, or other camera, is caused by the opening and closing of this pneumatic shutter.

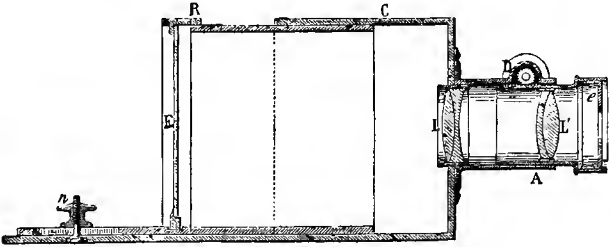


FIG. 52.—CROSS SECTION OF PHOTOGRAPHIC CAMERA.

A cross section of a photographic camera is shown in Fig. 52. Here, the image-forming lens, instead of consisting of a single converging lens, is formed of two lenses L and L′, each of which is formed of two different kinds of glass, and is known as an achromatic lens. A camera with such lenses is capable of producing a much more satisfactory photograph than one employing a single lens only.

Another form of optical apparatus that requires but a single lens for its operation is a magic lantern. This is an apparatus with which I imagine many, if not most, of my readers are familiar. It consists of means for thoroughly illumining an object, generally a photograph, that is, preferably, coloured with transparent colours and placed before a convex lens at its shorter conjugate focus. The image of this object is received on a distant screen in a darkened room where it can be seen at the same time by many people. Since the object is always placed before the image-forming lens in an inverted position, the image received on the screen, at its longer conjugate focus, is both magnified and erect.

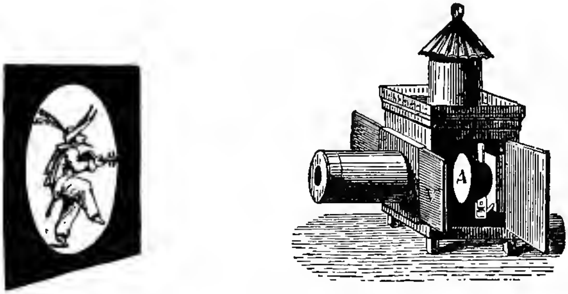


Fig. 53.—Magic Lantern.

In order that the object shall be thoroughly illumined, a convex lens, known as a condenser, is placed between the source of light and the object in order to throw a large quantity of light on it.

A common form given to the magic lantern is represented in Fig. 53. The image-forming lens is placed in a horizontal tube attached to the front of the concave reflector A so as to throw a strong light on an object placed on a slide at V, at the shorter conjugate focus of the image-forming lens.

Fig. 54 represents the arrangement of lenses and the concave reflector of this apparatus. The image-forming lens is placed at C, and the condensing lens at B, in front of the reflector A, while the picture slide, generally a photograph, is placed at V so as to receive light on its surface.

The magnifying power of a magic lantern is equal to the distance of the image-forming lens from the screen divided by the distance of the lens from the object. If, for example, the screen is 100 times further from the object than the image-forming lens, the magic lantern will have a magnifying power of 100 diameters. It is evident, therefore, that in order to obtain a great magnifying power in magic lanterns the focal length of the image-forming lens should be small, and the screen fairly distant from the lens.

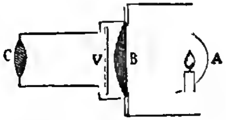


Fig. 54.—Arrangement of Lenses and Reflector in Magic Lantern.

Although I have spoken of the image-forming lens of the magic lantern as consisting of a single lens, yet in fine instruments this lens is formed of a number of lenses, since in this manner it is not only possible greatly to decrease the focal length, and by obtaining a wide lens to permit the passage of a considerable quantity of light, but it is also possible to obtain images of objects that are practically devoid of false colourations and false outlines.

Where a considerable magnification of an exceedingly small object is desired, a form of magic lantern known as a solar microscope is employed. This is called a solar microscope because the source of light it employs consists of a beam of sunlight reflected from the surface of a mirror. This instrument, however, does not differ in its image-forming lens from an ordinary magic lantern, except that this lens, possessing a very small focal length, causes a great magnification of the object that is being examined.

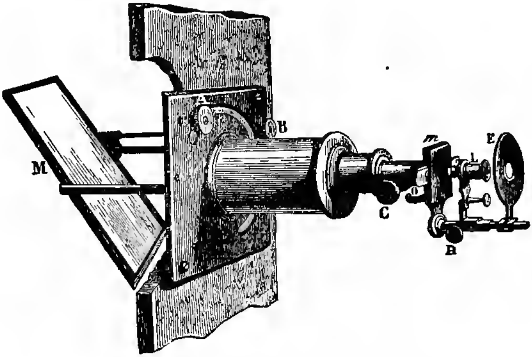


Fig. 55.—Solar Microscope.

Fig. 55 represents a well-known form of solar microscope. Here, the microscope is attached as shown to a plate placed over an opening in a shutter of a room. The light employed is a beam of sunlight reflected from the surface of a mirror M, placed on the outside of the room and inclined so as to throw a beam of light directly into the tube containing the condenser and the image-forming lens.

The direction taken by the beam of light as it is reflected from the mirror and passes through thé apparatus is represented in Fig. 56. As the beam is reflected from the mirror M it enters the condensing lens, from which it is thrown on the surface of the small object that is to be magnified, and its image is received on the distant screen. You will understand that the condenser employed in this instrument does not consist of a single lens l, but an additional lens placed as shown near the object. The object to be magnified is placed between two parallel plates of glass at *m*, and is held firmly between them in position in any suitable manner. The image-forming lens employed consists of a number of lenses that form the magnified image of the object on the distant screen. Focusing screws C and D, are provided so as readily to obtain a sharply magnified image on the screen.

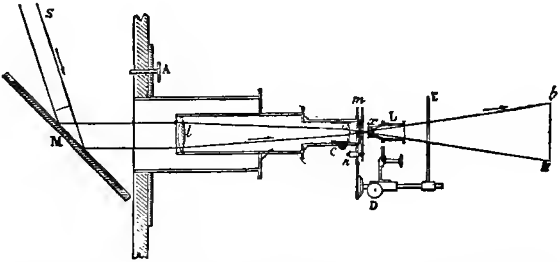


Fig. 56.—Direction of Light Through Solar Microscope.

The use of a beam of sunlight, for the illumination of the solar microscope, affords a strong and steady light, free from false colouration and, therefore, far more satisfactory than any artificial light. In order that sunlight may be employed for this purpose, it is necessary that means be provided to prevent the motion of the earth on its axis, from changing the direction of the beam of light, otherwise the beam would fail continually to pass through the apparatus, and would require a constant and annoying necessity for adjustment. This is accomplished by means of a device that so alters the inclination of the mirror as to maintain constant the direction of the ray reflected from its surface, so that it will always pass directly through the instrument. A clockwork is employed to alter the inclination of the mirror, in a manner similar to that already described in the equatorial mounting of the astronomical telescope. In this way the mirror is always pointed so as to cause the sunlight continually to pass through the lenses, notwithstanding the rotation of the earth on its axis.

There is another difficulty that must be overcome in the use of sunlight for illumining the objects observed in the solar microscopes. The sunlight is accompanied by heat, and this heat is sufficient in amount possibly to ruin the object that is examined. This difficulty, however, can be removed by causing the beam of light to pass through a strong solution of alum in clear water. In this way the heat is absorbed by the solution and the light permitted to pass through without any appreciable loss in intensity.

The solar microscope, or, as it is also called, the projecting microscope, possesses the advantage of being able to exhibit the microscopic details of a small object to a large audience. It is able, for example, to throw on a large screen the highly magnified images of the animalculæ that may exist in a drop of water. You may probably have seen at popular lectures a drop of water, highly magnified, in which appear all sorts of horrible monsters. The impression created that this is a drop of ordinary water is far from correct. Our actual drinking water, goodness knows, is at times bad enough without making it any worse, but by no means does it begin to come near this "faked" drop of water that is thus masquerading as ordinary water. It has often been secured only after great effort on the part of the so-called "scientist" who usually exhibits it.

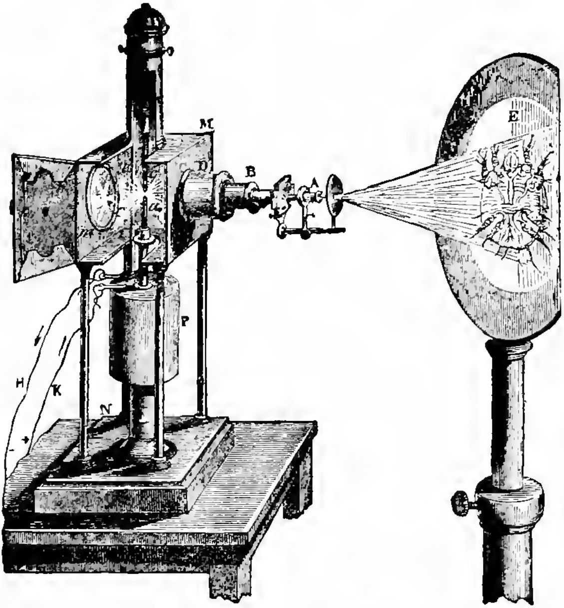


Fig. 57.—Photo-Electric Microscope.

Since, of course, the solar microscope is of no use during cloudy weather, or at night, some other powerful source of light must then be employed, when minute objects are to be greatly magnified. For this purpose the photo-electric microscope is employed. This differs in no respect from the solar microscope except that, instead of using a beam of sunlight, a powerful light known as the electric arc light is employed.

A photo-electric microscope is represented in Fig. 57. Here the source of light employed consists of a brilliant bow or arc of light formed by passing a powerful electric current between two vertical carbon rods placed at *c, a,* as shown. The light from the carbon arc, which by the way is the same as the arc lights that are employed for the illumination of streets, not only falls directly on the object that is to be magnified, but by passing through the condensing lens placed in the tube at D, is also reflected onto the surface of the condenser from a reflecting mirror *m,* placed back of the object. In this manner, the pencils of light passing through the tube of the instrument DB strongly illumine the object and permit its highly magnified image to be thrown on the distant screen by means of the combination of image-forming lenses shown at A.

CHAPTER XI

THE HUMAN EYE

By far the most important optical instrument to us is the eye, since by it we are enabled to see the world of matter that lies outside us. As an optical instrument, the human eye resembles a camera obscura. It consists of a dark chamber provided with a converging lens placed in an opening in the front immediately opposite a screen that receives the images of objects situated outside the eye.

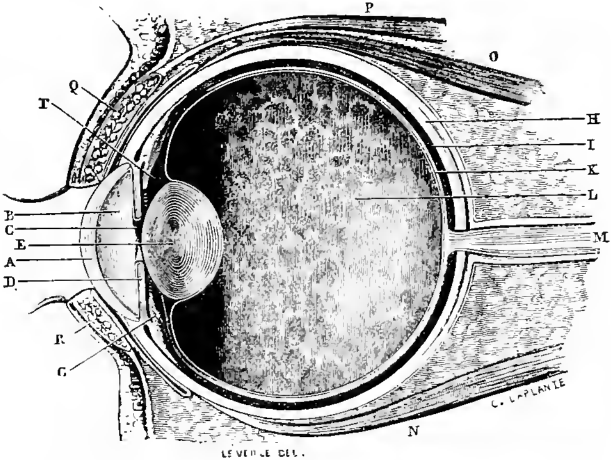


FIG. 58.—LONGITUDINAL SECTION OF THE HUMAN EYE.

In Fig. 58 the general structure of the human eye is represented as it would appear if cut in two vertically. The eye consists of a nearly spherical ball, somewhat less than an inch in diameter, that is able to turn in any direction in its socket. Although the eyes of some people appear much larger than those of others, yet this is not so much due to difference in size, as to the differences in the amount of the ball that can be seen projecting beyond the lids.

With the exception of the opening in front, the ball of the eye is opaque and consists of a coat known as the white of the eye, or the sclerotic coat. It is represented in the above figure at H. The front portion of the sclerotic coat is transparent, and forms what is called the cornea. This is shown in the above figure at A. The cornea has the shape of an unusually convex watch crystal.

Immediately back of the cornea is an opaque coloured portion called the iris. The iris is circular in shape and is provided at its centre with a circular opening called the pupil, that acts as a diaphragm. Instead of being clumsily operated by the hand, as is the diaphragm of most optical instruments, the iris is automatically operated by the amount of light that falls on it. When it receives more light than usual, the iris automatically decreases the size of the pupil; or, in other words, the pupil contracts, shutting out the light to such an extent as to ensure the proper illumination of the image. When, however, the amount of light falling on the iris is smaller than usual, the pupil automatically dilates and thus increases the amount of light that is permitted to enter the eye. These movements are beyond the will of the person, and are automatically determined by the amount of light that falls on the iris.

They are of great value, since an object cannot be seen distinctly unless its image is illumined by the proper quantity of light. If the amount of light is either too large, or too small, the image will appear blurred and indistinct.

The iris takes its name from the fact that it forms what is called the coloured portion of the eye. In some cases, the iris is black, in others, brown, gray, or various depths and shades of blue. That you may surely know the portion of the eye called the iris, I suggest you try the following experiment that will enable you not only to examine the iris of one of your eyes, but also both to see the position of the pupil, and at the same time to observe the wonderful manner in which it is able automatically to dilate and contract, as the amount of light falling on the iris varies.

The name iris, by the way, has been given to this part of the eye from Iris, the swift messenger of the gods, who was afterwards personified as the rainbow.

Hang a small looking glass on the wall immediately below a gas bracket. Carefully examine the colored portion of either of your eyes by looking at the image formed in the glass, and note particularly the extent of the pupil's opening. Now, turning the light down to the smallest amount that will still permit you to see the pupil, note the wonderful manner in which the pupil dilates or increases in diameter. Then turn the light up and observe how the pupil contracts; and then remember the wonderful optical instruments you possess and be careful you do not abuse them, for they are the only eyes you will ever get.

Immediately back of the pupil is a lens E, known as the crystalline lens. As you can see from the figure, this lens is more curved or convex on the back than in front. It consists of a number of concentric layers of transparent material, like the successive coatings of an onion. These layers gradually increase in density from the outside towards the centre, and thus decrease the tendency of the lens to produce false outlines in the images it forms; otherwise, the rays that fall on its outside portions would converge too much.

Between the cornea and the crystalline lens is a cavity divided by the iris into two portions or chambers that are filled with a watery liquid called the aqueous humour. These chambers communicate through the opening of the pupil. A larger chamber or cavity L, back of the crystalline lens, is filled with a transparent jelly-like material known as the vitreous humour. This chamber is enclosed, except at the front, by an opaque coating I, called the choroid coat, that is rendered intensely black by means of a black colouring matter.

On the inside of the choroid coat, on a small space opposite the crystalline lens, is an exceedingly sensitive portion of the eye called the retina. The retina acts as a delicate curtain or screen that is provided for the reception of the images formed by the lenses of the eye. It consists of a network of the fibres forming a continuation of the nerve of vision, known as the optic nerve, which is represented at M as entering the eye in the position shown. The nerve spreads over that portion of the eye immediately above it, as a delicate network of terminals that receive the images formed by the eye and then transmit them to the brain. This screen has received its name of retina from a Latin word *rete,* meaning a net.

Although as I have described the human eye it may seem to be a somewhat complex apparatus, as indeed it truly is, yet it consists practically of a darkened box or chamber, provided in front with an opening for the insertion of the image-forming lenses, and, nearly opposite the opening, of a screen for receiving the images thus formed. Although in reality all the media of the eye—the cornea, the aqueous humour, the crystalline lens, and the vitreous humour—act as a succession of lenses that refract or bend the rays of light while passing through the eye so as to bring them to a sharp focus on the retina, yet they practically act together as a single converging lens. The crystalline lens may be regarded as the principal image-forming lens of the eye; so that, shorn of all its complexity, the eye is merely a darkened chamber, or camera obscura, with a lens in front and a screen at the rear, to receive the images of external objects.

As you know, in most optical instruments, instead of employing single lenses a number of separate lenses are employed. This is exactly what is done in the case of the eye. Besides the crystalline lens with its concentric layers of materials of varying density, we have the cornea, the aqueous humour, and the vitreous humour, all of which act together as a single lens capable of producing those images, on which our knowledge of the world of matter outside of us is so dependent.

I need hardly tell you that, since the ball of the eye is only about an inch in diameter, and the principal lens that produces images on the retina is situated inside the eye, all objects seen by the eye are necessarily situated much further from the crystalline lens than the retina is.

In other words, the objects seen by the eye are situated at its longer conjugate focus. Consequently, the images received on the retina must be situated at its shorter conjugate focus, and must, therefore, be much smaller than the objects themselves. They must, moreover, be inverted, and must be formed on the retina in an upside-down position.

Certain conditions are necessary in order that the image formed on the retina shall be able to produce an impression on the brain so as to be distinctly seen. Unless this image is sharply focused on the retina, the object will either be invisible, or will be seen so indistinctly as practically to be unrecognisable. Now, since the eye can see objects when situated at distances varying from many miles to a few inches only, it is evident that, unless the eye were provided with some kind of focusing apparatus, there would be but a single distance in front of it where objects could be distinctly seen. Either beyond or nearer than this distance, all objects would be indistinct. A person would not know what was before him until he had come within a certain distance of the object. You can readily understand how such an incomplete and insufficient optical instrument would limit a man's ability to see what was going on around him and thus necessarily seriously retard his development.

Fortunately, man has been provided with so wonderful an optical apparatus that he is able literally in the twinkling of his eyes (for it is by twinkling his eyes that he focuses them) distinctly to see either distant or near objects with almost equal distinctness. Let me explain to you now how this wonderful change is brought about.

If, when you have been looking at some distant object, you suddenly direct your eyes to a nearer object, you will become conscious of making an effort to see that object distinctly, and in a very short time you will find yourself able to see it distinctly. Now, what you are doing is this. You are doing something with your eyes that will permit the image of the nearer objects to fall sharply on the retina. In ordinary optical instruments there is only one way in which it is possible to do this; i. e., by focusing the lenses and so varying their position until the image of the object is brought into the desired position. It was at one time believed that what the eyes do, when making changes that enable them to see a nearer object very distinctly, is actually to push the crystalline lens to-and-fro through more short distances, and so enable it to bring its image sharply on the retina. It is now, however, known positively that what is done, when an effort is made to accommodate the eyes for different distances, is actually to change the amount of curvature or convexity of the crystalline lens. This power of "accommodation," as it is called, is very wonderful, and is far beyond anything that man has been able to contrive.

Let us now see how the human eye acts on the diverging pencils of light coming from distant objects, so as sharply to focus their images on the retina. Suppose that AB, Fig. 59, represents a distant object, and that diverging pencils of light, coming from the extremities of this object, enter the eye by passing through the cornea, which, as you remember, is set like a watch crystal in an opening in the front of the ball of the eye. This pencil of light undergoes refraction not only while passing through the cornea, but also while passing through the aqueous humour, the srystalline lens, and the vitreous humour. Now, if the eye has been properly focused by accommodation, for the distance of the object AB, there will be formed a sharply focused image *ba*, on the retina. This image, as we have seen, must be both smaller than the object and inverted.

It probably seems odd that all images are received in an inverted position on the retina. That this is actually so can be proved by taking the eye of a recently slaughtered ox, cutting away the sclerotic and choroid coats, so as to expose the retina. On placing this eye before an opening in the shutter of a darkened room, an inverted image of the distant object can then be distinctly seen on its retina.

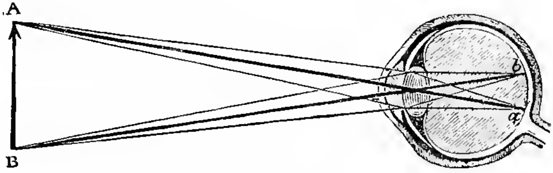


Fig. 59.—Action of Eye on Pencils of Light.

I will not attempt to explain to you just why it is that we do not see images of external objects upside-down. Indeed, I doubt very much whether any one could give a satisfactory explanation of this curious fact. With many others, I am disposed to believe that the real explanation is that we actually see objects upside-down, but that, having been accustomed to doing this all our lives, we do not perceive anything strange about such images. Should we see an object right side up, which can be done by means of a simple experiment with a lens, we would probably declare it to be upside-down.

I know that physiologists generally believe that it is by means of a number of branchings and inversions of the optic nerve that the brain is enabled to receive the impression of an erect image. But for my part I gravely doubt the correctness of this explanation, and am by no means alone in this opinion.

The explanation as to the branchings of the optic nerve regards the brain as another eye examining the image. I believe that the image on the retina so acts on the brain as to give it the impression of external objects in the same position as regards our bodies, as that our sense of touch informs us of. Having thus become acquainted by touch with a certain position of the object seen, we are afterwards enabled to determine this by the retinal images alone.

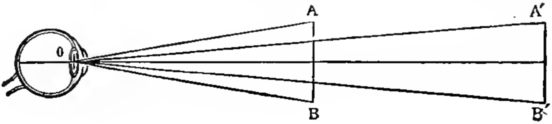


Fig. 60.—Visual Angle.

But the human eye not only distinguishes or sees distant objects. It is also capable of forming an idea of their relative size and distance. Let us endeavour to understand how this is possible. The angle under which an object is seen, or the angle formed by straight lines drawn from the centre of the crystalline lens to the extremities of the object, is called the visual angle. This angle, as represented in Fig. 60, is the angle AOB. As the visual angle decreases, the apparent size of the image decreases. In the above figure, as the distance of the object increases, the visual angle becomes smaller so that the image A′ B′ is smaller than that at AB.

But we look at objects, not with a single eye but with two eyes. There is, therefore, another angle that must be taken into account; namely an angle known as the optic angle. This angle is the angle formed by a straight line passing through the centre of the pupil and the crystalline lens in each eye to the object itself. It is evident that the greater the distance of the object from the eye the smaller will be the value of this angle.

Our ability to estimate the distance and size of objects depends on a variety of circumstances, the principal of which are the values of the visual angle and the optic angle, the comparison of objects of known size with the objects examined, as well as the differences in the distinctness of the image, as influenced by the details of the objects that can be seen after the light has passed through a greater or less depth of air due to the distance of the objects.

Suppose, for example, you are looking at a distant object, the relative dimensions of which are unknown to you. If, by chance, you happen to see in the image some object such as a man or a horse, whose usual size is known, your mind immediately makes an estimate of the size of surrounding objects by comparison with the dimensions of the man or the horse. You say unconsciously to yourself that the object at which you are looking is so many times the height and breadth of the man or the horse.

Another way in which the mind estimates the distance and size of an object is by the amount of conscious effort that is made in so directing the two eyes to the object as to be able to see it distinctly. In other words, the estimation of size and distance is by means of the value of the optic angle.

Again, the distinctness of the image as regards the detailed parts that can be clearly seen, forms a very common method by which the eye estimates the distance of objects. If one who has been accustomed nearly all his life to viewing objects through the comparatively dusty air generally existing near the level of the sea, views them through the clearer air of the higher mountain regions, or through the wonderfully clear air that so frequently characterises the Arctic and mountainous regions generally, the details of the visual pictures are so wonderfully clear that an erroneous estimate is apt to be made of the distance of such objects. Indeed, they are frequently judged to be but a few miles distant when their actual distance may be thirty or forty miles.

It is important to note in this connection the case of people who have been blind from birth by reason of an opaque crystalline lens or cataract. Skilled surgeons are now able in almost every case to restore such persons to sight by the removal of this lens. When the eye has healed after the operation, by employing convex spectacles the loss of the crystalline lens is compensated for, and normal vision is secured. Although the images are then properly formed on the retina, yet such people are invariably unable to estimate size and distance until they have had some experience in learning how to use their restored sight.

In discussing the magnifying power of lenses, attention was called to the fact that in order to obtain the most distinct vision, the object examined must be situated at a certain distance from the eye, and that this distance, though varying in different people from ten to twelve inches, could, perhaps, be taken on the average at a distance of ten inches from the eyes. It will be interesting here to note some other conditions that are necessary in order to ensure the most distinct vision.

In the first place, in order to see an object distinctly, it is necessary that the object be situated at such a distance from the eye as to produce a sharply focused image of some appreciable size on the retina. The image formed on the retina is always very small, but, unless it is of sufficient size to cover an appreciable portion of the nerve fibres, it can not be transmitted to the brain as a distinct image. In other words, it is necessary that a certain area of the retina shall have the light fall on it; otherwise no image will be seen.

In the next place, the image on the retina must be properly illumined. If the amount of light is insufficient in quantity, the image is not transmitted to the brain. If the amount of light is too great, the image transmitted will appear blurred and indistinct.

The distance at which an object can be seen depends not only on the amount of illumination but also on the colour of the object. When illumined by full sunlight, a white object can be seen by normal eyes at a distance of about 17,250 times its own diameter. If lighted by diffused daylight, it can be seen at only about half this distance. A blue coloured object is visible at a still smaller distance.

The distance an object can be distinguished is greatly influenced by its colour as well as by the colour of the background against which it is seen, the object being seen at the greatest distance when the contrast between its colour and the colour of the background is the most marked. It is for this reason that different colours are employed for signal flags for use at sea and for use on the land. Red, yellow, and blue flags may be employed at sea, according to whether the background is the blue of the sky or water, or whether it is the dull grey of the clouds or of the ruffled water surface. In the same way, the colours employed for railroad signals are frequently red, green, and white. These colours can be seen with different degrees of distinctness against the green background of the foliage during summer, the white covering of the snow in winter; or, in places, the dull yellow colour of the uncultivated ground.

CHAPTER XII

SPECTACLES AND EYE-GLASSES. SOME PECULIARITIES OF EYESIGHT

ALTHOUGH, as I have pointed out on several occasions in the preceding chapters, the human eye is a wonderful instrument, yet, in some respects, it possesses errors or faults even in what would be regarded as perfectly normal eyes. At the most, however, these defects are trifling when one considers the uses to which the human eye is put, and the fact that it is an instrument possessing life, and therefore must, like all our organs, have a condition corresponding to the condition of bodily health.

I have no patience with certain scientific men who are so impressed with their own knowledge and importance that they do not hesitate to cast a slur on the All-Wise God, who not only created man, but also planned the human eye and gave it to him for the acquisition of knowledge from the physical world that exists outside of him. I especially remember reading a statement made by a very distinguished scientist who declared that if a workman had sent him so imperfectly constructed a piece of optical apparatus as the human eye he would have sent it back with a rebuke for the clumsiness of its construction!

Passing by the almost insufferable conceit of such a statement, I would say that the eye, like all other portions of the human body, represents a structure that requires, for its continued efficient use, both the maintenance of physical health, as well as the utmost care in its use. If, therefore, people, through errors in their own living, or even as the result of errors committed by their ancestors, possess abnormal or diseased eyes, they should accept them, not as the result of bad workmanship, but as the punishment that properly results from the transgression of physical laws. In the case of the eye, as with other organs of the human body, it is only by its long-continued and proper use that its functions can be preserved. The criticism, to possess any weight whatever, should not have ignored the eyes of the earlier people, as they more nearly came from the hands of their Creator; for I have no doubt that, like the birds and other creatures of the woods and air, our early ancestors possessed eyes which, not being injured by incorrect habits of living, were far more nearly perfect optically than are the eyes of most people to-day.

The images formed by the lenses of normal eyes are sharply focused on the retina. In the abnormal eye, the images fail to be brought to a sharp focus and therefore appear blurred or indistinct.

There are three principal defects of human vision. In one of these, objects cannot be distinctly seen unless they are brought within six or eight inches of the eyes or nearer. Such eyes are said to be myopic or near-sighted, and are unable to see ordinary objects distinctly across the street, or, indeed, in different portions of a large room.

The cause of myopia, or near-sightedness, is the too great converging power of the eye, that thus brings parallel or slightly diverging rays to a focus before they fall on the retina. This defect is also due to the excessive length of the eyeball in the direction of a straight line passing through the centre of the cornea, the crystalline lens and the retina. In other words, near-sightedness is due to the ball of the eye being longer than that of the normal eye.

In order to ensure distinct vision for a myopic or near-sighted eye, a concave lens is employed as a spectacle glass. Without the use of such lenses it would be necessary to bring the object examined so near that its rays could enter the eye under a considerable divergence, and thus permit the otherwise too greatly converging lens of the eye to bring the image to a sharp focus on the retina. Of course, such a method would be impracticable. It is easy, however, for a myopic eye to be made practically normal by the employment of concave lenses placed in suitable spectacle frames. The diverging powers of concave lenses will cause the rays to diverge, and thus, as shown in the above figure, cause the image to be formed on the retina. To do this, care must be taken to employ concave glasses of sufficient diverging power to overcome exactly the too great convergence of the myopic or near-sighted eye.

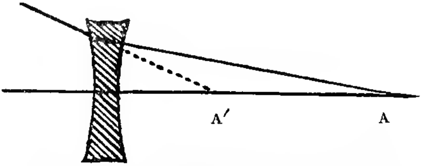


Fig. 61.—Action of Concave Spectacle Lens.

Some idea of the manner in which concave spectacle glasses act to overcome near-sightedness may be had from the examination of Fig. 61. Here A represents the position of a small object, and A′ the position of its image when seen through a concave spectacle lens placed as shown.

Another defect of the eye is presbyopia or long-sightedness. This defect is common with old people, whose eyes become flattened by reason of a hardening of the crystalline lens, due to structural changes that decrease the quantity of fluid it contains and make its converging power so feeble that the images of objects are brought beyond the retina and are, therefore, indistinctly seen. Such an eye is known as a presbyoptic or far sighted eye; or, since, as above remarked, this defect is common in old people, it is sometimes known as old-sight.

Far-sightedness, besides being due to the feeble converging power of the crystalline lens, is also sometimes caused by the eye being too short, from front to back. Far-sightedness, which is a common defect in the eye-sight of old people, begins to show itself by their finding it necessary in reading a book or a newspaper to hold it much farther from their eyes than usual. When not caused by disease, the defect can be completely remedied by the use of convex spectacle glasses; for such glasses, as has already been shown, adding to the too feeble converging power of the crytalline lens, sharply focus the image on the retina.

In the preceding chapter, I have explained the manner in which the eye is able to accommodate itself for objects at different distances, by producing a change in the curvature of the crystalline lens. Now people, when old, do not possess the power to accommodate the eye to different distances as readily as they did when young, so that it is necessary for them to employ two sets of glasses, one for far-sight, and the other for reading, or near-sight.

In order to avoid the necessity for frequently changing spectacles for distant objects and for reading, a device known as bifocal spectacles is now very generally employed. As shown in Fig. 62, bifocal spectacles consist of a pair of glasses AA, the focal lengths of which are suitable for distant objects, and a pair of smaller lenses *bb*, cemented by Canada balsam to the lower portions of A, A. Sometimes, however, bifocal glasses are formed by grinding the proper surfaces for the reading lenses on the lower surface of the long-distance glasses. Sometimes the same result is obtained by fusion. This possesses the advantage, at least some people *think* it is an advantage, of not letting others know they are obliged to wear bifocal spectacles. It also possesses the real advantage of avoiding the difficulties that are frequently apt to occur when a thin film of air works its way between the glass and the Canada balsam that cements the two surfaces together, thus rendering the vision indistinct.

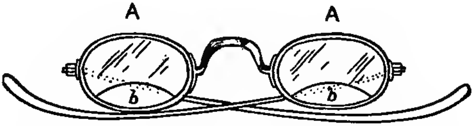


FIG. 62.—BI-FOCAL SPECTACLE GLASSES.

Another defect of eyesight is what is known as astigmatism. In this defect the rays of light are refracted to a different extent in different directions. In other words, an eye affected by astigmatism is unable to see straight lines unless they extend in certain directions. Sometimes, for example, such eyes can only see straight horizontal lines, and are unable to see distinctly lines extending in a vertical direction. Other eyes, however, can distinctly see the vertical lines but are unable to see horizontal lines.

Astigmatism is caused by differences in the length of the eye. When a perfectly normal eye looks at two straight lines that cross each other at right angles, both the horizontal and vertical lines can be seen with equal distinctness. If, however, the eye is astigmatic, then one of the lines only is seen distinctly; the other is blurred. In other astigmatic eyes, however, the horizontal lines will be distinctly seen and the vertical lines will appear blurred.

The defect of astigmatism may exist in any direction between the horizontal and the vertical. Various means are employed for determining the amount and the direction of the astigmatism. One of the commonest consists of the use of what is known as an astigmatic dial. This consists, as represented in Fig. 63, of a number of straight lines radiating from the centre of the dial of an ordinary watch or clock face. When such a dial is used by a person with normal eyes, all these diverging lines can be seen distinctly as straight lines. When, however, the dial is examined by a person whose eyes possess astigmatism, only some of the lines can be seen distinctly, the others appearing blurred or indistinct, thus showing the direction in which the eyes are astigmatic.

Astigmatism is a defect that can be easily remedied by the use of a cylindrical lens. Glasses for astigmatism should be worn constantly. Since the direction in which the eyes are affected by astigmatism is apt to change during changes in the general health, as soon as people with astigmatism feel that their glasses are failing to permit them readily to see straight lines in all directions, they should promptly have their eyes tested for the change in its direction. Then the cylindrical lenses may be properly placed on their glasses to overcome this defect.

There is another defect of the eye known as strabismus or "squint-eye." This is due to the extraordinary strength of the muscles that control the movements of the eyes in certain directions. Instead of the two eyes being directed forward, as normally, they are turned in different directions, very commonly inwards towards the nose. This not only gives an unpleasant appearance to the face, but, what is more to the point, prevents distinct vision. Since this defect is due to excessive strength of the muscles

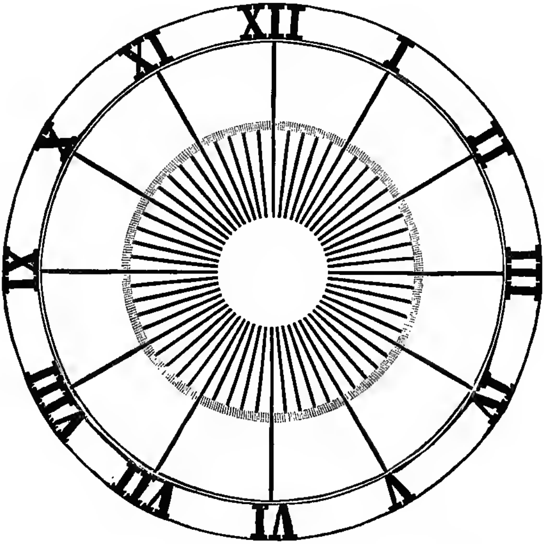


FIG. 63.—ASTIGMATIC DIAL. (L. W. FOX.)

that are employed for turning the eyes in different directions, strabismus can be completely cured by cutting sufficiently across those muscles that possess too great strength until they are of equal strength with the others. When this operation is skilfully performed, the eyes entirely lose their squint. It should, of course, be performed only by an expert surgeon. Glasses are sometimes successfully employed to correct this defect.

The images produced on the retina by the crystalline lens do not instantly disappear when the light causing them is cut off, as, for example, by closing the eyes, or by momentarily holding an opaque object between the eyes and a distant object, but continues or persists for some time. You have probably noticed that, if a lighted stick be rapidly swung around in a circular path, as soon as the motion becomes sufficiently rapid, the lighted portion is no longer seen as a single luminous point but as a continuous circle of fire. In a similar manner, if you carefully watch the drops of falling rain, you will not see them as separate spherical drops but as liquid streams. This is due to the fact that you continue to see the drops in a number of different positions.

Another example of the persistence of vision is seen in the case of a meteorite rapidly moving across the heavens. It is not seen as a single luminous body but produces a luminous track across the sky.

Perhaps the best example of persistence of vision is one that you can try yourself by a simple experiment. If you rapidly wink your eyes, that is, open and close them as often as you can in a given time, you can nevertheless see the different objects at which you are looking. In this, as indeed, in all these cases, the images, by reason of the persistent impressions they make on the brain, do not entirely disappear with the light that forms them.

As we shall see in another chapter, many curious effects result from the fact that images tend to remain on the retina for some time after the light that has caused them has disappeared. Some of these effects seem almost magical.

In order that an image formed on the retina shall be able to produce an impression on the brain, it is necessary that it shall remain for a certain time. It is not enough that an image sharply focused and of a definite size shall be formed on the retina. Unless it remain there for a sufficient time, it is unable to produce any effect on the brain.

It is impossible to detect the motion of a cannon ball when viewed at right angles to the direction of its path, since, although by reason of its prodigious velocity the light from it is able to form an image on the retina, yet this image does not remain long enough to produce any effect. If, however, the projectile is moving away from the observer, it is distinctly visible, since then its image remains on the retina for a length of time sufficient to enable it to transmit its effects to the brain.

In a similar manner we are also unable to detect such motion as that of the hour hand of an ordinary clock or watch. On large clock dials, however, the motion of the minute hand can be readily seen, and, as you well know, the motion of the second hand of a watch is still more easily seen. For the same reason it is impossible to see the motion of the heavenly bodies in their orbits.

There is a curious defect of some eyes that prevents them from distinguishing certain colours. While such eyes can see some colours, yet they are blind to others. In a few rare instances, people have been found who are colour-blind to all colours. While they can see coloured objects, yet these images are entirely devoid of colour. To such people the beautiful colours of the natural world are completely invisible, natural objects appearing as differences of light and shade only. Generally, however, colour-blind people are blind to certain colours only, and can distinctly see all the others. For example, some colour-blind people are unable to distinguish between greens and reds. Others, though less frequently, are unable to distinguish between blues and yellows.

Colour-blindness is sometimes called Daltonism from the fact that the celebrated philosopher, Dalton, who was affected with this disease, was the first to call attention to its existence, as well as to show how its presence could be detected.

Dalton was unable to distinguish bright crimsons or reds. To him these colours appeared as drabs or greys. You can imagine the surprise and shock this good Quaker occasioned, when he gravely entered his meeting-house with his shapely limbs encased, not in his usual grey, as he fondly thought, but in stockings of the brightest and gayest crimson.

When present in such persons as railroad men or sailors, colour-blindness is a serious defect; for their duties oblige them to be able readily to distinguish between the colours of signal lights and flags. Their inability to tell readily a green from a red light, or either of these from an ordinary white light, might easily wreck a train or a ship, and thus cause great loss of life.

The ophthalmoscope, an important piece of optical apparatus, is employed for the examination of the human eye, in determining its healthy or diseased condition. The ophthalmoscope was invented by Prof. Helmholtz, a well-known German physicist, in 1851. As represented in Fig. 64, this apparatus consists of a concave spherical reflector M, provided at its centre with a circular aperture about one-sixth of an inch in diameter, and with a converging lens B that is held in front of the person whose eye is being examined.

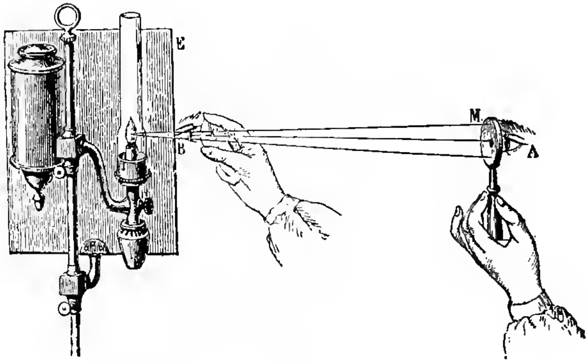


FIG. 64.—HELMHOLTZ'S OPHTHALMOSCOPE.

In employing an ophthalmoscope, the person who is being examined is placed in a dark room alongside a lamp provided with a screen E, placed so as to keep the head in the dark. The observer places his eye at A, immediately back of the opening in the spherical reflector that he holds so as to throw a conical pencil of light into the lens B, held in the other hand, before the eye which is to be examined. In this manner the back of the person's eye is thoroughly illumined, so that it is possible to examine fully its general structure and appearance.

Although the image of distant objects may be focused sharply on the retina, yet when the illumination is sufficiently bright, the light produces an impression that is not limited to the illumined area, but extends some little distance beyond this limit. This peculiarity is known as irradiation, and has the effect of causing the image of an object of a light colour, when seen on a dark background, to appear much larger than it is in reality. For example, the white square represented in Fig. 65, when seen on a black background, appears much larger than the black square on a white background shown in the same figure, although the two squares are exactly of the same size.

Fig. 65.—Irradiation.

It is irradiation that causes the stars to appear much larger than they really are. In the same way, the brightly illumined crescent of the two- or three-day-old moon, seems to extend beyond the darkened portions and presents the curious appearance of holding the moon in its grasp.

CHAPTER XIII

HOW WE SEE SOLID BODIES

You may naturally ask why it is, since we look at an object with both eyes, and an image is therefore sharply focused on the retina of each eye, that we see a single image only and do not see the two separately. This question is not an easy one to answer. The explanation is probably as follows:

The optic nerve, when it comes from both the right and the left lobe of the brain, divides or branches, sending its fibres into the retina of each eye. There is, therefore, a correspondence of the fibres, so that an image formed in either eye produces its effects through the branches from the other eye. The two images thus simultaneously affect corresponding points of the brain, and, when the two eyes are properly focused on an object produce a single image only.

That the retina of each eye is thus provided with branches of the optic nerve which extend to the other eye may be seen by the fact that, when light is permitted to fall on the retina of one eye only, it produces a contraction of the pupil of the other eye.

Unless, however, both eyes are properly focused on the object there will be double vision, and not single vision. It is well known that persons who are either drunk or have almost fallen asleep, and have, therefore, lost the power of properly directing both eyes to the same object, invariably see double. Double vision is also sometimes caused by certain diseases of the brain or the paralysis of the muscles of the eye.

But an image of an object received on the retina of the right eye is not exactly the same as that which is received from the same object on the retina of the left eye. Although the eye is examining a single object, yet if it possesses solidity, or, in other words, if it has length, breadth, and thickness, or extends in three dimensions, then, although generally speaking the image formed in each eye is the same, yet the image of the right eye will possess details that are wanting in the image of the left eye, and the same thing is true of the image in the left eye. This is an important fact that I wish you to understand thoroughly. You may readily assure yourself of its correctness by a simple experiment.

Hold one of your hands before your eyes, say your left hand, so that when examined by the right eye with the left eye shut you can see the thumb, all of the first finger and part of the middle finger, which hide the other fingers, the palm of the hand and some of the fingers foreshortened. The back of the hand, however, is quite invisible. Now, keeping the hand in this position, close the right eye and open the left eye. You will now see the thumb, forefinger nearly hiding the others except, however, as you can now see at the back of the hand and some of the fingers back of the forefinger foreshortened. The image of the hand formed by the two eyes is evidently not the same for the right eye as for the left. It is because these images are different that when they are seen by the brain as a single image they possess the appearance of solidity.

Another simple experiment will, perhaps, throw additional light on this matter. Bend a visiting card in the middle like a triangular roof, and place it before you on a table with a gable end facing the eyes. Then observe it alternately with the right and the left eye, rapidly opening and closing one eye after the other. You will then see the card in two different positions. When seen by the right eye, only one side of the flat roof will be seen strongly illumined and the other side will be in the shadow. When seen by the left eye only, the opposite side will be seen distinctly and its other side will be in the shadow; during these movements the card will seem to move from side to side. We know by experience that such appearances can only be produced by objects that possess solidity, or occupy space in the three dimensions of length, breadth, and thickness. Therefore, when we see such images, the mind properly comes to the conclusion that the objects producing them possess solidity. Indeed, so true is this that it is possible to make drawings on two separate pieces of flat paper that shall represent respectively the appearance presented by the front and the right and left sides of a solid object. If these are placed before the two eyes so as to enable them to be seen simultaneously as a single object, they will appear in a marked manner to possess solidity, although, as we know, the single image is due to the combination of two perfectly flat pictures.

In order to obtain the correct image of a solid body, it is necessary to observe it with two eyes, so that the two images produced shall differ in some details from each other. Indeed, without binocular vision; i. e., vision with two eyes, perfect vision is, so far as the appearance of solidity is concerned, an impossibility.

There is also another principle that is employed by the mind in determining the correct appearance of an object. This is as follows: When the images formed by the two eyes are combined into a single image, the mind comes to the conclusion that it is a solid object that is being viewed for the following reasons: It is evident that a solid object may be regarded as consisting of a number of separate points situated at different distances from the eyes. While being examined, the two eyes are rapidly and insensibly changing their angle of convergence; or are changing what we have already defined as the optic angle. During this rapid accommodation of the eyes to different distances, the mind is sitting in judgment as to the difference in position of these different portions of the object, and is thus enabled to form an estimate of the amount and character of its solidity.

If you have followed the above explanation, you will understand that, in order to obtain a correct view of a solid object, it is necessary that the object should be examined by both eyes. This is the same as saying that binocular vision, or vision with two eyes, is necessary in order to see a solid object correctly, and since, except when reading and during a few other occupations, all the objects we look at are practically solid, binocular vision is necessary for perfect vision. While, therefore, a person who has lost the sight of one eye, may have fairly good vision, yet such a person can never have vision as complete as if both the eyes were present.

It can be shown that vision with both eyes possesses the following advantages:

(1). The field of vision; i. e., the area seen, is enlarged. This is almost self-evident.

(2). The image possesses a marked appearance of depth because it is seen from two different positions.

(3). By the perception of the extent it is necessary to converge the two eyes on the object in order to see it distinctly, there is secured a better idea of its distance and size.

(4). When, as is frequently the case, one eye possesses defects, these defects are to a certain extent compensated by the image formed by the better eye.

An interesting form of an optical apparatus has been invented by Sir Charles Wheatstone by means of which it is possible readily to combine in a single picture the two separate pictures that are formed by each of the eyes, and thus obtain the appearance of solidity. This apparatus is called the stereoscope. If you will give me your close attention I think I can make it clear to you how this instrument operates.

The word stereoscope is derived from two Greek words meaning "to see solid." As its name indicates, the stereoscope is an apparatus by means of which two perfectly flat pictures can be seen by the eye as a single picture that will, therefore, appear to possess solidity.

Let us suppose that two pictures have been taken of a solid object on two separate sheets of paper, or on two perfectly flat surfaces just as they would appear to the left and right eyes when viewed in the usual manner. One of these pictures is the picture as it appears to the right eye, and the other, the picture as it appears to the left eye. The two pictures are placed in the box of the stereoscope, as represented in Fig. 66, before two eye-pieces. These eye-pieces consist of two lenses, so constructed that the rays of light coming from the pictures are refracted or bent outward to the same angle. On entering the eye of an observer, they appear to come from a single picture placed in the centre of the box. They will, therefore, permit the eye to observe them just as if they consisted of a single picture formed by the combination of the two separate pictures, and will, consequently, possess the appearance of solidity.

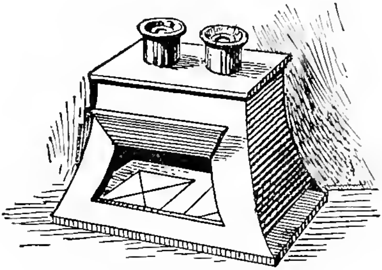


Fig. 66.—Stereoscope.

Fig. 67 shows the shape of the two eye-pieces or lenses employed in the stereoscope. These eye-pieces are placed as represented with their thinner edges facing each other at AA′. The rays of light coming from corresponding points in the two pictures at PP′, after their passage through the lenses at LL′ enter the eye of an observer as if they came from a single point O.

It is easy to take two photographs of a distant solid object, by means of two separate cameras placed at the proper distance apart so as to obtain pictures as they would appear when viewed by the right and left eye respectively. By afterwards placing these pictures in the stereoscope, we can obtain an image of a building, or other object, that will make it seem to stand out from the paper as if it possessed actual solidity.

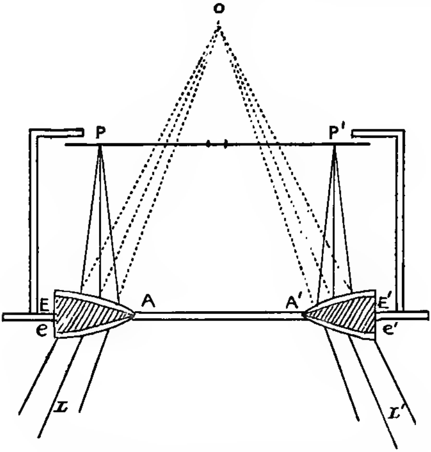


FIG. 67.—ACTION OF STEREOSCOPE.

In taking photographic pictures of buildings, or of landscapes, the two cameras may be placed on a stand a few feet apart. Unless care is taken not to take the pictures too far apart, an appearance of unnatural solidity will be given to the stereoscope image.

In the stereoscope, as it was first invented by Sir Charles Wheatstone, the two separate pictures were caused to produce the effect of a single image by means of two suitably placed mirrors.

The appearance of solidity that can be obtained from perfectly flat pictures when viewed through a stereoscope is so wonderful that I would strongly urge you to take the first opportunity that may present itself to look through a good stereoscope, for I am sure what you will see will amply repay you for the trouble you have taken.

The fact that any two pictures may be caused to produce an impression on the eye as a single picture, can be made to afford you and your friends no little amusement. When you get hold of a stereoscope, put a friend's photograph on one of the supports, and on the other a sketch of a cigar, a pair of moustaches, a fool's cap, or what you will. A little practice will enable you to place the drawings or the photographs in such a way that your friend will appear in the stereoscope to be smoking a cigar or wearing moustaches or a fool's cap. In a similar way, you can combine any number of details and get a variety of amusing results.

CHAPTER XIV

THE NATURE OF LIGHT

WE are now sufficiently acquainted with the principles of light to be able to make some intelligent inquiries into its nature. As you know, the ancient Greeks and Romans were not well informed concerning natural phenomena. They had some very queer ideas as to the nature of light and the manner in which the eye is able to see distant objects. At one time it was believed that, when one wished to examine a distant object, it was only necessary to send out rays of light from his eyes in such a direction as to fall on the object to be examined. This light, after touching different parts of the object, came back and, entering his eyes again, gave him all the information he desired. Such a ridiculous theory of the cause of light and vision is of course no longer believed. We know to a certainty that the rays of light coming from a distant body are not produced by the eye, but by the object itself, if it be a luminous object, or by some other source of light if it be an illumined object; that these rays, passing through the lenses of the eye, form a sharply focused image on the retina and so produce an impression on the brain in the manner we have already described.

I can only take time to discuss the two principal theories that have been proposed to account for the phenomena of light. I am the more willing thus to limit this inquiry since these theories will give you practically all that is worth hearing about. One of them is now entirely rejected. The other is now practically believed in by all.

The theory that is no longer credited was known as the emission or corpuscular theory of light. It was propounded, and ably defended, by Sir Isaac Newton, the great English philosopher. This theory has so many defects that it would have been overthrown much sooner than it was, had it not been for the great genius of Newton, who stood ready to defend it, and to endeavour to meet the many objections that were brought against it. I wish to say here, that in discussing the nature and phenomena of light, as well as in different parts of this Wonder Book, I have availed myself of the excellent order of arrangement of the topics on this subject found in the "Notes on Light," that Prof. Tyndall prepared for the use of those who attended his lectures on Light and Electricity at the Royal Institution of London.

The corpuscular or emission theory asserted that light is due to exceedingly small particles or corpuscles that are shot off from all luminous or illumined bodies with an almost inconceivable rapidity. These particles or corpuscles are assumed to be so small that they are able to pass through the pores of transparent media, such as glass or water, almost as readily as if these media had no existence. The particles, too, were believed to enter the delicate structure of the human eye, and, passing through its various parts, to strike finally against the retina without causing the slightest injury or harm.

One of the most powerful arguments against the emission theory of light is the enormous velocity with which light is known to pass from place to place. If the corpuscles possess even the slightest weight, they must necessarily destroy the delicate structure of the human eye, when they are hurled against it with the enormous velocity with which light travels. It is a simple matter of calculation that a body, possessing the weight of but one grain, if moving with the velocity of light, would possess a momentum, or quantity of motion, equal to that of a cannon ball weighing 150 pounds and moving with a velocity of 1,000 feet per second. Even supposing the corpuscles to possess an almost negligibly small weight, yet if they move with the velocity of light, they would, beyond question, not only shatter the delicate structure of the eye, but would even mow down all objects on which they fall, as would the balls from a battery of guns. We could then no longer speak of the merry sunshine, since even a momentary exposure to it would result in sudden death. This objection certainly makes the emission theory of light untenable.

Another objection that has been brought against the corpuscular theory is connected with the reflection of light. Think for a moment how this theory must explain what takes place when, as in Fig. 68, a ray of light AB falls perpendicularly on a plane mirror at B. As you know, the light is reflected back again in the opposite direction to that at which it struck the mirror, that is, from B to A.

Now, if light consists of minute corpuscles that are shot off from luminous bodies with the tremendous velocity of light, it would be necessary to believe that these particles immediately lose their tremendous velocity when they strike the mirror and immediately afterwards are thrown off from the surface in the opposite direction with a velocity that is not in the slightest degree smaller than that at which they struck. On this account, then, the emission theory of light is also untenable.

But the difficulties do not stop here. In the case of transparent substances, such as glass or water, only a portion of the light is flung off from the surface. Generally a larger portion enters the medium, and passes through it.

Now if a luminous corpuscle on striking obliquely against a transparent substance, such as a plate of glass or a body of water, is attracted, then it is drawn towards the surface like a projectile is drawn towards the earth, so that it should move through the refracting medium with an increased velocity. But it can be shown, by actual measurements, that when a ray of light undergoes refraction in a dense medium, such as glass or water, it moves through the medium, not with an increased but with a decreased velocity. On this count, also, we find the emission theory of light is untenable.

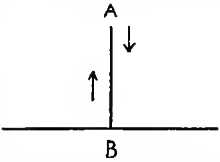


FIG. 68.—A SERIOUS OBJECTION TO THE CORPUSCULAR THEORY OF LIGHT.

Before the corpuscular theory of light was finally overthrown, many severe battles were fought between some of the world's most eminent scientific men. Newton's corpuscular theory of light was upheld by such famous men as Laplace, Malus, Brewster, and Biot. Equally celebrated men such as Huyghens, Euler, the mathematician, Thomas Young, the celebrated English philosopher, and Fresnel, a celebrated French physicist, opposed this theory and asserted that light, like sound, consists of wave motions in a medium. I will not take time to tell you about the exceedingly interesting and often heated discussions that took place between these men during this controversy, especially since I have already pointed out the principal objections against the corpuscular theory of light, objections that finally led to its complete overthrow.

Let us now try to understand the theory of light that has replaced the corpuscular theory, and is now accepted by scientific men all over the world. This is known as the undulatory theory, and teaches that light is caused by a wave motion in the universal ether.

One of the greatest difficulties that stood in the way of the earlier acceptance of the undulatory theory of light was the enormous velocity light is known to possess. As is well known, the velocity with which light waves are capable of passing through any medium depends on the relations existing between the elasticity and density of that medium. The greater its elasticity, the greater will be the velocity with which the waves will pass through it. Then, too, the smaller its density, the greater will be its velocity. Any medium, therefore, to be capable of transmitting the waves that produce light must not only possess an exceedingly great elasticity, but at the same time must have an exceedingly great tenuity. Now a medium possessing these properties is known to exist in what is called the luminiferous ether, because of its ability to transmit waves of light. The great objection to the wave theory of light, therefore, has been removed.

It is now believed by practically all scientists that this ether is a highly elastic medium so extremely tenuous that it can pass freely through such substances as glass, water, or even the densest metals. It is imponderable or possesses absolutely no weight. You must not suppose, however, that it in any respect resembles the atmosphere of the earth, or any such traces of that atmosphere which exist in any very high vacuum.

It is called the luminiferous ether because light is transmitted through it by means of waves, or to-and-fro motions that take place at right angles to the direction in which the ray of light is advancing. And this is very curious, since, so far as we know, vibrations of this character; i. e., transverse vibrations, are only set up in solid media. The ether is called the universal ether because it exists everywhere, not only throughout the space between stars and other heavenly bodies, but also between the very small particles called atoms or molecules of which all matter consists.

According to the undulatory theory of light, the small particles or molecules of all luminous bodies are in a condition of constant vibration, moving towards and from one another with great rapidity. These to-and-fro motions of the molecules set up in the surrounding ether minute waves that, spreading in all directions, produce what is known as light.

It can be shown that light waves in the luminiferous ether vibrate at right angles to the direction in which the rays of light are advancing. In this respect light waves differ from the waves that produce sound, for sound waves move in the same direction as that in which the sound is travelling, or, in other words, are longitudinal waves; while the vibrations that produce light move at right angles to the direction in which the light is travelling, and are transverse waves.

Both the refraction and the reflection of light can be thoroughly explained in accordance with the undulatory theory. When you are older, and are perhaps studying more deeply the undulatory theory of light, you will be able to see how completely it accounts for such difficult matters as refraction, the polarization of light, etc.

Let me now tell you how the velocity of light has been measured. This velocity is so extremely great that it might be supposed that no time whatever is required for light to pass from place to place; or, in other words, that this passage was absolutely instantaneous. Indeed, it was not until some time in 1675 or 1676 that it was proved by Roemer, the celebrated Danish philosopher, that light actually requires time to pass through space. At this time Roemer was engaged in company with Cassini, the celebrated French astronomer, in observing the eclipse of one of the moons or satellites of the planet Jupiter. You may know that Jupiter, which is situated at the enormous distance of 475,693,000 miles from the sun, has four separate moons. Roemer was watching the moon that lies nearest the planet. He could see it as long as it was moving in front of the planet, but as soon as it had reached the edge, and turned around towards the opposite side, it would disappear like a suddenly extinguished candle. After a certain time, however, it would reappear on the opposite edge of the planet.

By the appearance, disappearance and reappearance of this moon of Jupiter, Roemer ascertained the exact time it required to make one revolution or complete passage around the planet. In this way, after having made no less than 100 separate observations, he knew just when the planet should reappear after it had disappeared at one edge. Now these early observations were made when the earth was in that part of its orbit which is nearest Jupiter. On repeating the observations, six months afterwards, when the planet was in that part of its orbit farthest from Jupiter, to his great surprise Roemer found that the satellite was fully fifteen minutes late in reappearing, and correctly inferred that it was because the light had a greater distance to pass through.

Roemer reasoned concerning this as follows:

"Had I been able to remain at the other side of the earth's orbit, the moon might have appeared always at the proper instant, an observer placed there would probably have seen the moon fifteen minutes ago, the retardation in my case being due to the fact that the light requires fifteen minutes to travel from the place where my first observation was made to my present position."

Thus Roemer concluded that, as the earth approached Jupiter, the retardation should gradually become less, until, when the earth reached the position it had when the first observations were made, there should be no retardation at all. He found these suppositions true by actual trials. In this way Roemer determined that light travels with a velocity of 192,500 miles per second.

But the velocity of light can be measured in an entirely different way. This is by means of the principle known as the aberration or wandering of light. If we move quickly through a shower of raindrops, when the separate drops are falling vertically downward, they will not appear to be falling straight down, but will seem to be inclined to an extent that depends on the velocity with which we are moving. It was in a similar manner that in 1723, the English astronomer Bradley, showed that the motion of the earth through space produced a similar deviation in the direction of the rays of light. Now, if we know the velocity with which we are moving through the falling raindrops, and measure the angle at which the drops appear to have moved out of their vertical direction, we can calculate the velocity or speed with which the drops are falling. In a similar manner, knowing the velocity with which the earth is moving in its orbit, we can calculate the velocity with which the light is moving, and in this manner can show that light moves with a velocity of 191,515 miles per second, a value quite close to that calculated by Roemer.

But the velocity of light has been actually measured by means of rapidly revolving mirrors. In this manner, a French physicist, named Fizeau, measured its velocity as 194,677 miles per second, while later and far more reliable measurements made by another Frenchman, named Foucault, place the velocity of light at 185,177 miles per second.

Before turning from the two theories of light let me mention the wonderful experiments of William Crookes, an English chemist and physicist, to be fully described in the next chapter. While he was attempting to obtain in a vacuum the molecular weight of thallium, a new element he had discovered, a beam of sunlight falling on the scale pan caused the balance to act as if the light actually possessed weight. It looked as if the light consisted of something like corpuscles that, striking the plate, moved it in the direction in which they had been travelling. Indeed, had this thing occurred during the time of the controversy respecting the corpuscular theory of light it would probably have been hailed as demonstrating the correctness of the theory. But the corpuscular theory had been completely overthrown at this time; and, moreover, Crookes, who was greatly skilled as an experimental philosopher, was not long in discovering its cause. You will find a full description of this experiment in the next chapter.

CHAPTER XV

THE LIGHT MILL

There is a curious piece of apparatus, somewhat resembling a windmill, that when placed in sunlight begins turning rapidly on its axis like an ordinary windmill. It has, therefore, received the name of the light mill.

The appearance of the light mill, or, as it is generally called by scientists, the radiometer, is represented in Fig. 69. It consists of a small wheel, formed of four discs of some material like mica, attached to the ends of two arms placed at right angles to each other, and so supported on a needle point as to be capable of rotating with but little friction. The opposite faces of the disc are covered respectively with lamp black, that readily absorbs the light and heat of the sunlight that falls on them, and with some highly polished reflecting material, like silver, that readily throws off both light and heat. The light wheel thus formed is placed inside a glass globe, which is exhausted to a very high vacuum and then sealed by the fusion of the glass. When the light mill is placed in the sunlight, the faces of the discs that are coated with lamp black soon become much hotter than those which are coated with silver, and the wheel is set into rapid rotation in a direction against or away from the blackened discs.

When the sunshine is bright and warm, this rotation soon becomes so rapid that the number of discs on the wheel cannot be recognised by the eye.

The light mill was invented in 1861, by Sir William Crookes. The invention was brought about in so curious a manner that I am sure it will greatly interest you.

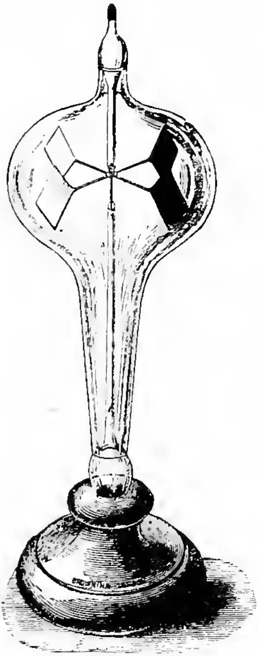


FIG. 69.—LIGHT MILL OR RADIOMETER.

It appears that Crookes had discovered in the residue of a sulphuric acid manufactory in the Hartz Mountains, a new chemical element that, when placed in a colourless flame, imparted to it a bright greenish colour. Crookes therefore named this element thallium from a Greek word meaning "a twig."

Now when a chemist discovers a new element, one of the first things he does is to determine what is called its atomic weight; that is, the weight of its atoms as compared with the weight of the atoms of other elements. It is important to know this exactly because no two chemical elements possess the same atomic weights.

Knowing that when a body is weighed in air it loses a weight equal to the weight of the air it displaces, and that this loss varies with the density and temperature of the air, Crookes determined to weigh his specimen of thallium in a vacuum. He, therefore, constructed a metallic box with a plate of strong glass on the top, and another glass plate on one of the sides, and placed the balance that was to be employed for the weighing inside this box, and connecting the box with an air pump he removed as much of its air as he could. Crookes had considerable experience in the use of air pumps, and knew how to obtain a very high vacuum, and so in this experiment he succeeded in getting nearly all the air out of the box.

He then proceeded to get the exact weight of the thallium by placing a small specimen on one of the scale pans of the balance, and adding weights to the other pan until the two sides exactly balanced, and the arm of the balance came to rest in a true horizontal position. In this way the exact weight of the thallium was obtained, independently of the buoyancy of the air.

Now it happened, at a moment when the two pans exactly balanced each other, that a sunbeam, passing through the glass side of the vessel, fell on one of the balance pans only. The pan receiving the sunbeam acted as if it had suddenly become heavier, and, descending, threw the other pan upwards.

It was fortunate that this observation was made by a man of cool intelligence. By an ordinary man it would probably have been misunderstood, and this experiment might, perhaps, have been given to the world as proof positive that a sunbeam possesses weight. But Crookes was a physicist as well as a chemist, and was therefore able to deal properly with the phenomenon.

It must, however, be acknowledged that at first Crookes was greatly astonished at what he saw.

"Can it be possible," he argued to himself, "that a sunbeam has weight? It certainly looks so. I must study this matter carefully."

At last he discovered that the movement of the illumined pan was not due to an increase in weight caused by the sunbeam falling on its surface, but to certain movements set up by the heat of the sunbeam in the minute traces of air remaining inside the vessel.

Let us endeavour to understand how a beam of sunlight falling on a balanced scale pan in a vacuous space could throw it out of equilibrium. The molecules, or the very small particles of which air is composed, are never at rest, but are constantly moving to-and-fro in straight lines. During these motions they collide against one another, or strike the walls of the vessel in which the gas is held. In either case they are at once thrown off from one another, or from the walls, and continue to move in straight lines until they again collide.

The number of times a molecule will collide with another molecule in a given time, depends on the number of molecules contained in the gas, as well as on the speed at which they are moving. The greater the number of molecules in a given volume of gas, the greater the speed with which they are moving, the greater will be the number of collisions per second.

But if the gas in the vessel is rarefied by removing some of it by an air pump, then, the number of molecules being fewer, there will be fewer collisions per second, and the molecules will move through longer paths before they collide or strike one another.

If the air in the vessel is so rarefied that it only contains 1/1000 of its original number of molecules, the number of times the molecules would collide would be one thousand times less than formerly. Consequently, the distance through which any molecule might move without colliding with a neighbouring molecule, would be one thousand times greater. In the same way, if the rarefaction is such that the space contains only 1/1,000,000 of its original number of molecules, the number of collisions would be only 1/1,000,000 that of the original number, and the space through which each molecule would be able to pass without striking a neighbouring molecule would be 1,000,000 times greater than before.

Now Crookes discovered that, when a vessel containing a gas is exhausted to such a degree that its remaining molecules are able in their to-and-fro movements to pass from the surfaces of objects placed in the vessel to its walls without striking against one another, the exhausted space will possess properties differing markedly from spaces filled with ordinary air; for in such spaces the to-and-fro motions of the molecules will be able to produce mechanical effects, such as setting the light mill in rapid rotation.

Let us try to see how a beam of sunlight falling on one of the arms of a balance placed inside a box containing matter in the radiant or ultra-gaseous condition, could cause an apparent increase in weight. Although this is generally considered an extremely difficult matter, it is in reality quite simple.

In the first place it must be remembered that the molecules of a gas move to-and-fro in straight lines, and that the speed of these motions increases as the gas becomes hotter. If, therefore, a space filled with ultra-gaseous matter contains surfaces at different temperatures the molecules that come in contact with the heated surfaces will be thrown off from these surfaces with greater force than from the cooler surfaces.

Let us first suppose that everything inside the box is at the same temperature. Then the molecules would fly off from the upper and lower surfaces of the scale pans with equal force and in opposite directions; i. e., vertically upwards and downwards with the same force.

A stream of water or gas flowing out of an orifice in an open vessel, produces a back pressure against the vessel that tends to move it in a direction opposite to that in which the jet is flowing. This back pressure is sometimes called the reaction of the escaping jet.

Suppose, for example, the vessel D, filled with water, is suspended by a cord AB, as represented in Fig. 70, at X. When no liquid is escaping, the vessel will come to rest, with its suspended string in a vertical position AB. As soon, however, as a jet or stream of water is permitted to flow out from one of the sides, the back pressure, or the reaction of the escaping jet, will move the vessel from its vertical position into the position AB, and the amount of this deviation from its vertical position will depend on the size of the opening, as well as on the velocity with which the jet is escaping.

But it is evident that, if the vessel D, Fig. 70, suspended as shown, at X, be provided with two jets *a* and *b*, of the same size, on exactly opposite sides of the vessel, when such jets are permitted to flow, their reaction will tend to move the vessel with equal force in opposite directions, so that it will remain in a vertical position, although back pressures are acting on it, since these pressures are equal and opposite.

If, however, the volume of one of the jets as *a′*, at Y, Fig. 70, be increased, the amount of its back pressure will be increased, and, since these two opposite pressures no longer neutralise each other, the vessel will move in a direction towards the smaller pressure, and assume the position AD′.

Now coming back to the case of the gas on the upper horizontal surface of one of the scale pans of the balance in which Crookes was weighing the thallium, the air contained within the balance being in a highly rarefied condition, as long as the two opposite faces of the pan were at the same temperature, the molecular streams that were being thrown both directly upwards and downwards could produce no effect on the position of the pan, since they exactly balanced each other. As soon, however, as a beam

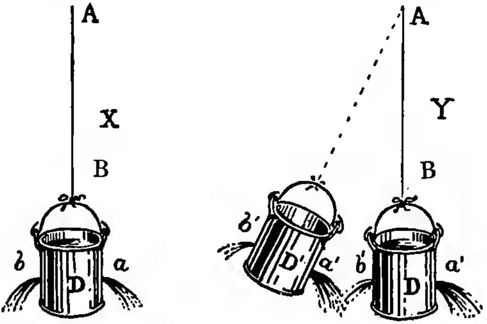


FIG. 70.—ACTION OF EQUAL AND UNEQUAL AND OPPOSITE DIRECTED JETS.

X, Action of equal and opposite directed jets; no deflection of vessel D—Y, Action of unequal and opposite directed jets; D moved in the direction of the smaller jet.

of sunlight fell on the upper surface of one of the pans, its temperature increased and the streams of molecules shot vertically upwards, being stronger than the opposite stream shot vertically downwards from the lower surface of the pan, the pan moved vertically downwards and thus acted as if the beam of light actually possessed weight.

Now it was the discovery of the peculiar motions of the molecules of gas in this highly rarefied condition, or as Crookes called it in the ultra-gaseous condition, that led him to the invention of the light mill or radiometer. This ingenious device as shown in Fig. 69 consists of a light wheel formed of thin plates of mica, supported as shown at the extremities of two cross-arms. The wheel is suspended on needle points so that it can move in a horizontal plane with very little friction.

When the discs are exposed, either to the sunlight or to the flame of a lighted match or candle, the light with its accompanying heat is absorbed by the blackened surfaces and thrown off from the silvered surfaces. The blackened surfaces therefore become heated, and the molecules which strike them are thrown off with a greater velocity than from those silvered. The wheel, therefore, begins to move, in a direction away from the blackened surfaces, and soon acquires an exceedingly rapid movement.

Had it been known several hundred years ago, the radiometer would certainly have been regarded as a great wonder and would probably have been claimed by the believers in the emission theory of light as proving the existence of corpuscles thrown off by luminous sources.

But heat is not the only agency by means of which molecular streamings can be set up in ultra-gaseous atmospheres. The same thing can be done by means of electricity.

When a cannon ball strikes against a plate of steel, considerable heat is produced. The same thing is true of less rapid motions. A skilled blacksmith can hammer a mass of soft iron, such as a horseshoe nail, so as to make it sufficiently hot to use it for lighting the fire of his forge. The streams of molecules that are thrown off from surfaces in ultra-gaseous atmospheres move with great rapidity and can raise bodies against which they strike to temperatures sufficiently high to enable them to emit light. If a small target, or plate of platinum, receives such molecular bombardment, its temperature may be raised even to a brilliant incandescence, especially if the surface from which they are thrown off is made concave in shape, so as to bring all the molecules to one point or focus.

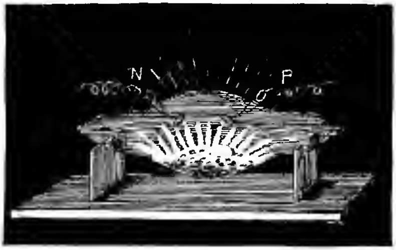


Fig. 71.—Phosphorescence by Electrical Bombardment.

In a similar manner, substances that possess the power of phosphorescence, or of becoming luminous by a short exposure to sunlight, can be caused to glow or phosphoresce, in the dark, by exposing them to molecular bombardment. If a phosphorescent substance, such as calcium sulphide, be placed inside a glass vessel, Fig. 71, containing air in an ultra-gaseous state, when a discharge from a Ruhmkorff coil is caused to pass between P and N, the movements of the molecules are sufficiently rapid when they strike against the phosphorescent material, to produce in it a bright phosphorescent light.

CHAPTER XVI

THE MAGIC WAND OF PRINCE PERCINET

You may remember my promise to show you something far more wonderful in light than the manner in which Prince Percinet, by a single touch of his magic wand, succeeded in sorting out and arranging in separate bundles the immense number of feathers from hundreds of different birds that had been thoroughly mixed together and crammed into a huge barrel. There were tens of thousands of feathers, many of which looked so much alike that poor Graciosa would never have been able, without help, to sort them out into separate bundles, and yet at a single touch of his magic wand, Prince Percinet caused the feathers to fly out of the barrel, and, in the twinkling of an eye, arrange themselves in separate parcels on the floor, without a single feather being out of place.

What Prince Percinet did with his magic wand was certainly a wonderful thing, but, now that we are sufficiently acquainted with the principles of light, I am ready to make good my promise of proving that he could make this magic wand do a far more wonderful thing.

We have seen that although a ray of sunlight, when passed through a plate of glass, the opposite faces of which are parallel to each other, is bent out of its course or refracted both on entering and leaving the plate, it will emerge parallel to its original direction. If, however, the opposite faces of the plate are inclined to each other; or, in other words, if the plate is wedge-shaped, then the ray of light on passing out of the prism will be bent out of its original direction. Now this wedge-shaped piece of glass, known in optics as a prism, is a magic wand far more powerful than Percinet's wand.

Since a ray of light passing through a prism is bent out of its original course, both while passing through the glass of the prism as well as through the medium outside it, if an object is viewed through a prism, it will necessarily be seen out of its true position. For example, if a lighted candle is viewed through a prism, it will appear out of its true position; for the rays of light suffer two bendings. Therefore, on entering the eye of the observer, they will appear to come from a candle considerably out of its true position. But this ability of a prism to change the apparent position of an object is by no means its most curious property.

If a beam of sunlight is permitted to enter a darkened room through a slot or opening in a shutter, as represented in Fig. 72, it will form a white or colourless image of the sun on the floor of the room at K. If, however, this beam is caused to pass through a prism P, placed as shown in the figure, it will not only be turned out of its original position, but the exceedingly great number of different kinds of rays, of which a beam of sunlight consists, will be turned out of their paths to different extents; so that, instead of producing a white image on the floor at K, it will be spread over the surface of the wall H, opposite the opening, as a wonderful band of rainbow colours shown at *v, i, b, g, y, o and r.* This band of colours is known as a spectrum, and since it has been obtained from a beam of solar light, it is known as a solar spectrum.

Although it may seem to you on looking at a solar spectrum that there are only a few colours, yet, in reality, the band consists of an exceedingly great number of separate colours that pass insensibly into one another. The solar spectrum is sometimes incorrectly spoken of as consisting of seven colours only; i. e., violet, indigo, blue, green, yellow, orange and red. In reality, however, each of these consists of bands containing a very great number of different shades or tints of violets, indigoes, blues, greens, yellows, oranges and reds.

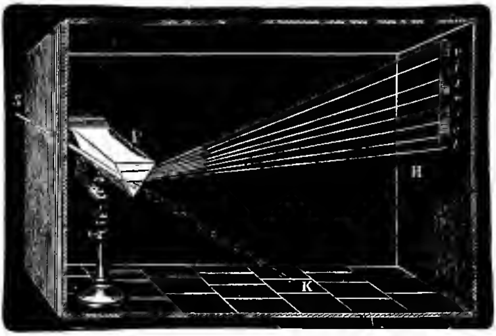


Fig. 72.—A Prism Sorting Out the Different Coloured Rays of Sunlight.

You will notice in the preceding figure, that the variously coloured rays have by their passage through a prism been turned to different extents out of the original direction of the beam, the violet rays being diverted from their course to a much greater extent than the red rays. As you can see, the violet rays occupy that portion of the spectrum which falls on the wall nearest the ceiling, while the red rays occupy the portion nearest the floor. The violet rays then undergo the greatest amount of refraction, or possess what is called the greatest refrangibility while the red rays are the least turned out of their course, or possess the least refrangibility. The order of refrangibility of the different colours of the spectrum, beginning with the most refrangible and ending with the least refrangible, is as follows: violet, indigo, blue, green, yellow, orange and red.

I wish especially to warn you not to imagine when I speak of red light, or violet light, that I mean a light of a single colour only. On the contrary, when I speak of the red or the violet of the spectrum, I am referring to bands or collections of thousands of separate reds or violets, which, for the sake of convenience, we have agreed to call red or violet light. And it is the same with orange, yellow, green, blue, or indigo light.

It is easy to prove that each of these bands consists of assemblages of different coloured tints; for, if the light is successively passed through a number of prisms, rays of different tints of red, violet, indigo, blue, etc., will be spread out on the surface of the screen or wall that receives the spectrum.

Imagine now that you are Graciosa and are in the room represented in the above figure and are looking at the spot of sunlight on the floor. This patch of light is your barrel of mixed birds' feathers which are to be sorted out and arranged in separate parcels. Even if the wicked stepmother has her hand on the knob, there is plenty of time for you to complete your task. By merely placing the prism in the position shown in the figure, so that the beam of sunlight, instead of falling directly on the floor, passes through it, you will perform the task in time to save yourself. For, lo, in an instant there appears on the wall an almost infinite number of separate rays or colours of the spectrum spread out in bands of separate parcels. Is not this a more wonderful thing than the fairy story? And fairy stories are told with the intention of being as wonderful as possible.

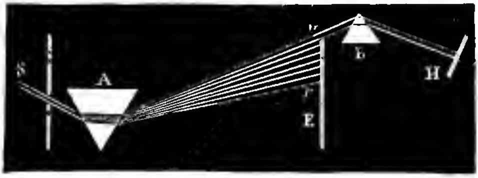
The separation of a beam of white light into its various constituents is known as dispersion. Sometimes the word diffusion is carelessly and incorrectly employed for the irregular scattering of light that takes place when it falls on a roughened or irregular surface. As, however, I have already pointed out, the irregular scattering of light is properly called dispersion.

The discovery of the power of a prism thus to separate sunlight into its constituent rays was made by the great Sir Isaac Newton to whom we have already referred, about the beginning of the year 1667. Newton had built his enormous reflecting telescope which, by the way, was one of the first telescopes of this character, and had experimented also with refracting telescopes, and, not being satisfied with the images formed by their lenses, was trying to improve them.

After considerable experimenting, Newton began to suspect that the trouble with the images formed in refracting telescopes was not due to the lenses, but might be caused by the light itself; that, perhaps, it was impossible to focus the rays coming from an object so as to prevent the formation of false colouration. He, therefore, began experimenting with a glass prism, placed in the opening in a shutter of a darkened room, thus permitting a beam of sunlight to pass through it. He found that, when permitted to fall on the opposite wall, after its passage through the prism, the light no longer had the appearance of white light but displayed colours. He thus discovered that a beam of sunlight does not consist of a single colour, but of a great variety of different colours. It was Newton who gave the name solar spectrum to the band of coloured rays thus produced. It was as early as 1667 that he discovered this magic power of a prism for separating and thus sorting out the almost innumerable colours that are present in sunlight.

During his experiments, Newton demonstrated, as you also could easily do, that when a beam of sunlight has been dispersed into bands of different colours, if any one of these bands of light is subsequently passed through a second prism, it does not produce another group of colours of the rainbow tints from the red to the violet, although it does separate the band into a number of different tints of the same colour. If, for example, the particular band we ordinarily call violet light is caused to pass through a second prism, what has seemed to the eye to be a single violet coloured ray is separated into a great number of differently tinted violet rays, having the general colour of violet, and only called violet collectively for want of a sufficient number of separate names to distinguish each of them. This, however, is the point I wish you to especially note. The violet light that has been separated from the beam of white sunlight by its passage through the first prism, although by no means a single kind of light, yet is an entirely different thing from the white light of the sun itself. Were it not different, then on its passage through the second prism it would also be divided into the light of the solar spectrum with all its colours between the red and the violet. But as we have seen, this separation does not take place. The light simply consists of a number of differently tinted violet rays.

The apparatus employed by Newton in these experiments is shown in Fig. 73. A beam of sunlight S, coming through an opening in a shutter of a darkened room, is passed through a prism A, so as to form a solar spectrum on the opposite wall at E. If a screen be placed so as to permit only the violet rays to pass through a second prism, B, there will be seen on a screen placed at H, a further separation of the violet rays, but no red, orange, green, blue or indigo rays will be produced.



· Fig. 73.—Newton's Experiment with Violet Light.

Naturally, you will ask why the magic wand of Percinet, or a prism, is capable of acting in this manner so as immediately to sort out the different coloured rays that constitute sunlight. This question can be easily answered. It is because the different coloured rays pass through the prism with different velocities, and, therefore, take different paths, and so fall on different portions of the wall.

This agrees with what I have already told you as the cause of refraction; i. e., that light is refracted and takes a different direction while entering a piece of glass, or a surface of water, from the air, by reason of the decreased speed or velocity with which it passes through the water or glass, as compared with its velocity in air.

It is because each of the different coloured rays of light passes through glass or water with velocities different from those with which it passes through air, that a prism is able to cause the rays to take different paths. They can no longer keep together, or as it were, side by side, as soon as they enter a medium like water or glass in an oblique direction, for some of the rays move through this medium much more rapidly than through air, and, moving at different speeds, must take different paths, and must, therefore, be separated or dispersed.

It is almost impossible to compare the speed with which this change could take place with so exceedingly slow a motion as the twinkling of an eye. Since light passes through air with a velocity of something in the neighbourhood of 186,680 miles a second, the time required to produce this change, and sort out the different coloured bundles of rays on the opposite wall, would be the time required for the light to pass through the prism and the distance between the wall, a distance say of about ten feet. Now since light can pass through 186,680 miles in a second, the time it would take to pass through ten feet in order to cause this change would of course be ridiculously less in duration than the wink of the eye.

As we have seen, light is due to a wave motion in the luminiferous ether, the ether vibrating very rapidly in paths at right angles to the direction in which the ray is advancing. The different coloured rays of the spectrum produce their different effects on the retina by reason of the differences in the rapidity of these wave motions. In other words, the different colours of light differ from one another in exactly the same way as the different notes in music. As you know, the strings on a piano differ both in length and thickness, those producing the shrill tones are short, thin, and tightly stretched; those producing the low or grave notes are long, thick, and less tightly stretched. The short, thin, highly stretched strings move to-and-fro when struck more rapidly than do the long, thick, and less tightly stretched ones that produce the grave tones. Now it is the same with different coloured rays of light. The red rays correspond to the least rapid to-and-fro motions of the ether, while the violet rays correspond to the more rapid to-and-fro motions.

Without entering into any further explanation of this matter, I would say it can be shown that a wave length of light, or the distance through which light advances during one complete to-and-fro motion of the ether, can be exactly measured, and that the actual lengths of the light waves required to produce the different colours are exceedingly small. These waves are so short that, when placed end to end, 40,000 of them would only extend through the length of an inch, in the case of the red ray; while in the case of the violet, it would require 58,000 of such rays placed end to end to extend over this distance.

Now, since light travels at the enormous velocity of 186,680 miles per second, there will, in the case of a red ray of light, be produced every second the number of separate waves or vibrations that could be crowded together, not in the length of an inch, but in the length of 186,680 miles, thus producing a number of vibrations per second that is indeed too enormous to conceive. This would make in the case of the red light something in the neighbourhood of (I am only giving the numbers roughly) 473,300,000,000,000 vibrations per second, and in the case of the violet something in the neighbourhood of 697,300,000,000,000 vibrations per second! In other words, when a ray of violet light enters the eye it is pouring waves or vibrations through its delicate structure that follow one another at such an enormous rapidity that 697,300,000,000,000 waves enter every second. If then the eye continues to receive violet light for a whole minute, for an hour, or for several hours, it should not be a matter of surprise that its retina gets fatigued or somewhat tired.

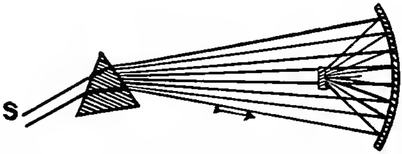


Fig. 74.—The Recomposition of Light.

If, by any means, the different coloured rays of the spectrum are again mixed together, so that they can all enter the eye of an observer at the same time, they are again capable of producing the sensation of white light, Suppose, for example, that all the coloured rays produced by the passage of a beam of white light through a prism be caused to pass through a double convex lens. Then these rays, being thus brought to a single focus, will produce a light exactly the same as that of the white light of the sun.

The same thing can also be done in the way shown in Fig. 74, where the spectrum or collection of different coloured rays produced by the passage of a beam of sunlight through a prism is caused to fall on the concave surface of a mirror. When all are brought to a single focus as shown, they will no longer appear of different colours, but will possess the characteristic white of ordinary sunlight.

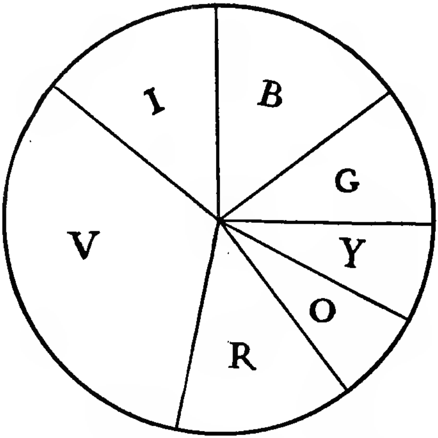


FIG. 75.—COLOUR DISC EMPLOYED FOR THE RECOMPOSITION OF LIGHT.

There are many other ways in which the separate colours can be brought together so as to produce white light. For example, if the different colours of the spectrum are caused to fall on a number of separate mirrors so as to be reflected to a single point on the ceiling of a room, there will be seen at that point, not the separate colours of the different rays, but a path of white light.

There is even a simpler method of producing white light by the mixing together of the different colours; or, as this process is sometimes called, by the recomposition of light in distinction from its decomposition or separation into different colours. If a blackened disc of cardboard has painted on its surface, in the spaces V, I, B, G, Y, O, R, in Fig. 75, the prismatic colours, and the disc be set into rapid rotation, it will appear, to an eye placed in front of it, not to be coloured in different segments but of a uniform white. Here the mixing of the prismatic colours is made in the eye of the observer; for, when the rotation is sufficiently rapid and one of the coloured segments comes in front of the eye, say, for example, the violet segment V, the eye does not cease to see the violet image when the disc has moved away from it, but by the persistence of the retinal image it continues, so that a violet coloured ring is formed on the eye. In the same way the other colours, the indigo, the blue, the green, the yellow, the orange and the red segments, I, B, G, Y, O and R, form continuous rings on the retina and, these being superposed on each other, produce on the eye the effect of white light.

CHAPTER XVII

COLOUR

You may be surprised to learn that a body does not possess colour in itself, but that its colour is due to the light that falls on it. A body has a white colour if it possess the power of throwing off all the colours that are present in sunlight. If, however, a body absorb some particular colour of sunlight, then the remaining light it throws off is no longer able to produce on the eye the effect of white, and the body appears to be coloured.

When all the light that falls on a body is absorbed, it appears black, because it throws off no light. If it partially absorb all the different colours, thus giving off a small proportion of each, it appears of a grey colour. A piece of coloured fabric, such as a piece of red flannel, or other red material, appears of a red colour because it absorbs all the colours of the light that falls on it but the reds. It is only the light that has penetrated some distance into a coloured body, such, for example, as a red fabric, that has its other colours absorbed. In many cases a small quantity of light is thrown directly off its surface. This light has none of its colours absorbed, so that there is mingled with the red light of a red body a certain amount of white light, and the same is true of any other opaque coloured body, such as a blue, an orange, or a yellow.

It is by no means an easy thing to obtain light of a single colour only from an opaque coloured body, such as a piece of red or crimson fabric. While such a body throws off mainly the red or crimson rays which have come from the light that has partially entered the mass, yet along with these rays there is nearly always a certain proportion of orange or yellow rays that have failed to be absorbed. Red or crimson fabrics, therefore, do not always throw off pure red or crimson rays, but generally have associated with them certain small proportions of orange and yellow coloured rays. Of course, red coloured fabrics differ from one another very greatly in this respect. Some throw off nearly pure red or crimson light, while others throw off red light mingled as above stated with varying proportions of orange or yellow rays. And then, as we have seen, there is always a certain varying proportion of white light directly thrown or reflected from the surface of the fabric. In some coloured fabrics the amount of this white light is comparatively large; in others it is quite small.

Coloured bodies, therefore, possess no colour of their own. They owe their colour entirely to the light that falls on them. Since they are capable of throwing off certain colours only, if some of these colours do not exist in the light by which they are illumined, they will not possess the same colour as they would when illumined by daylight. For this reason coloured bodies, examined by artificial light, often have an appearance entirely different from that they show by daylight. For example, in many forms of artificial light there is a preponderance of the red, orange and yellow rays, and too small a proportion of the blue and violet rays. While, therefore, such artificial light can give fairly true colour values to red, yellow and orange coloured fabrics, they are unable to give the true colours to fabrics of green, blue, indigo or violet.

That the colour of an object lies not in itself, but in the light which falls on it can be shown by the following extremely simple and yet wonderful experiment: An alcohol lamp, or a Bunsen burner, is practically non-luminous. If such a flame is permitted to fall on a small quantity of common table salt, or chloride of sodium, it becomes of an intensely yellow colour, its light consisting almost entirely of yellow light. If this light were passed through a prism there would not be obtained a continuous band or spectrum of different colours, as in the case of sunlight, but only a single colour, or, at the most, a few bands of different tints of yellow rays.

If, then, we colour the flame of a Bunsen burner, or an alcohol lamp, with common table salt, and employ this light in a darkened room where no other light exists, for the examination of different coloured objects, we will obtain some exceedingly curious results. For example, if a piece of red sealing wax, or still better, a piece of dark red flannel, is brought into the light of the yellow flame, it will appear quite black. The reason is evident. The wax or the flannel can only throw off red light, and since there is no red light in the yellow coloured gas flame, the wax or the flannel has no light to throw off, and, therefore, appears black.

But if a piece of yellow coloured fabric is brought into the light of the yellow flame, you will be surprised at the bright light it throws off; for the yellow fabric possesses the power of throwing off yellow light, and since there is an abundance of this coloured light in the luminous gas flame, that fabric can throw this light off readily and, therefore, appears as a bright yellow.

In a similar manner if sunlight be passed through a glass vessel containing a deep blue solution, obtained by adding an excess of ammonia water to a solution of blue vitriol, or sulphate of copper, we will have a light that consists almost entirely of blue rays. If different coloured objects are examined by this light we will find that, while blue fabrics are readily seen, other coloured fabrics throw off so little of this light that they appear either browns or blacks.

A curious effect is produced on the appearance of the human face when illumined by pure yellow light. The pleasing appearance of a healthy face or skin is due to its ability to throw off a certain amount of red light. The face of a dead person possesses a peculiar dull grey or leaden appearance, on account of the absence of the red light that in life is produced by blood circulating near the surface of the skin. Now in a room where there is no light except the yellow light of a sodium flame, there is necessarily a complete absence of these reddish rays. Faces, therefore, so illumined by this light present the ghastly appearance of the dead. I would advise you to try this experiment for yourselves, for it is exceedingly easy, and is capable of producing wonderful results. A Bunsen flame, or the flame of an alcohol lamp, is best for the purpose. But if you have any difficulty in obtaining either of these things, simply pour a small quantity of alcohol in a saucer and, throwing a teaspoonful of common table salt in the alcohol, thoroughly saturate a piece of common cotton lamp wick with the solution. When you set fire to the lamp wick, you will have the characteristic yellow coloured flame, and if different coloured fabrics or different coloured objects are examined by this flame in the dark, you will be surprised at the curious appearance they present. Reds and crimsons, of almost all tints, appear either as dull greys or blacks. Indeed, it is possible that in some cases the people to whom you are showing these experiments may think you have, through sleight of hand, been fooling them by adroit changes in the coloured fabrics. This, however, can instantly be disproved by holding in front of the fabric either a lighted match or a lighted taper. Either of these lights contains nearly all the colours of the spectrum, so that the reds and the crimsons of the objects at once appear and continue to be seen as long as the match or taper remains lighted. When it is extinguished, however, and the objects are only illumined by the yellow light, the peculiar browns and blacks instantly reappear.

Since white fabrics owe their colour, when illumined by sunlight, to their ability to throw off all the rays of the spectrum, they will, when illumined by light of a particular colour, such for example as red, yellow, green or blue, instantly appear of that colour. This fact is put to a practical use on the stage, at the theatre or the opera, in order rapidly to change the colour of the dresses worn by the ballet. If the dancers are clad in white, it is possible instantly to change the colour of their apparel by throwing different coloured beams of light on them. In this way, as you have probably often witnessed, marvellous transformations of colour are instantly brought about.

But there is another kind of coloured bodies; i.e., transparent coloured bodies. These bodies are transparent to certain colours only, so that when white light falls on them, certain of the colours are absorbed or quenched, and the remaining light which passes through is coloured. An example of transparent coloured bodies is found in plates of coloured glass. If a beam of sunlight is permitted to pass through a plate of deep red glass there can readily be obtained light that consists of nearly a red colour only. If a green body, such as a leaf, is illumined by this light only, it may appear nearly black. Unless, however, the plate of red glass employed is of a deep red colour, other rays besides the reds will pass through, such, for example, as the yellow or the orange rays, and even a small quantity of the green, in which case the green leaf may be visible. It will not, however, be of its ordinary green colour, but of a sickly grey, with only a suspicion of green, that will cause it to look very different from what it would if placed in sunlight.

Some substances possess the power of showing one colour by means of the light that is reflected from their surfaces, and another colour by the light that passes through them. Such substances are called dichroic, or two-coloured substances.

Some varieties of red aniline inks, prepared from certain coal tar colours, are dichroic. If a plate of glass be covered by a thin film of such a red ink it will appear of a deep red colour by the light that is passed through it, and of a bright green colour by the light that is thrown off from its surfaces. In a similar manner there are a number of dichroic blue aniline inks. Plates of glass covered by a thin layer of such inks appear blue by transmitted light, and orange or deep yellow by reflected light.

I must now explain to you some peculiar properties of what are called complementary colours. As we have seen, when all the colours of the solar spectrum are mixed together in any way which will permit them to affect the eye simultaneously, they will no longer appear as different colours, but will produce a sensation of white light, like ordinary sunlight. If, however, one group of colours, such as the reds, is removed, and the remaining colours are mixed together, the mixture will no longer be able to produce a white light, but will produce a light of a greenish blue colour. In a similar manner, if the yellow rays, or the band of yellows, be removed from the spectrum, the remaining colours when mixed together will produce an indigo blue.

Such colours are called complementary colours because they are the colours that are required to complement or fill out to the full measure of whiteness the colours that have been removed. Red and greenish blue are complementary colours. When mixed together they are capable of producing white. In a similar manner yellow and indigo blue are complementary colours. So also are orange and cyan blue, and greenish yellow and violet.

In one sense it may be said that white and black are complementary colours; for when mixed together they are capable of producing a colour that might be regarded as white, though it is more properly a grey.

We must carefully distinguish between the mixing of coloured lights and coloured paints or pigments. I imagine that most of you, at one time or another in your lives, have played with boxes of paints, and have probably learned, what all artists know so well, that by mixing different coloured paints together there can be produced a great variety of colours. For example, yellow and blue paints mixed together produce a beautiful green. If, however, you should mix yellow and blue lights together, you would get, not a green light, but a white light; for blue and yellow are complementary colours, and when complementary colours are mixed together, white light is the result. The reason for the difference in the colour produced by mixing different coloured paints and different coloured lights is as follows: When yellow and blue pigments are mixed together, the light that penetrates them a short distance has all its colours absorbed except the greens, and since the greens are the only colours that are transmissible, the colour of the mixture appears green. But when blue and yellow lights are mixed together, being complementary colours, they produce, as do all complementary colours, a white light.

A number of very wonderful results can be produced by reason of the fact that when the eye has looked steadily for a certain time on a given colour, it gradually loses its power to continue to see that colour, and becomes much less sensitive to that colour. You can easily convince yourself of this fact by the following simple experiment:

Stick a small red wafer at the centre of a sheet of white paper, and place it where it will receive a good illumination by white light. Fix the eyes steadily at the centre of the wafer so that they will not wander from it in the slightest degree. If after a few moments the red wafer is removed, and the eyes are still kept fixed at the place where it originally was, you will see in its place the image of a green wafer. What you are looking at is a perfectly white piece of paper. What you see is a greenish circle occupying the place where the red wafer was. Here is what has happened: the optic nerve has become so wearied by looking at the red that it is unable to see red any longer; so, although all the colours of the spectrum are thrown from the surface of the paper at the place where the red wafer was originally placed, the eye is unable to appreciate the red colours, and, therefore, sees the colour that would be produced by the removal of red from the white light. This of course will be greenish blue, for greenish blue is the complementary colour of red.

Similar effects can be produced by the use of coloured shadows. By the use of a plate of red glass a uniform red light or field can be obtained over the surface of a sheet of white paper. If now an opaque body, such as a lead pencil, is held in the path of the red light so as to throw a shadow on the paper, and on this shadow a small quantity of diffused light falls, it will no longer appear dark or black, but will take on a greenish blue colour; i.e., a colour complementary to that of the red light in which the shadow has been formed. In a similar manner, a faintly illumined shadow formed on a yellow field will appear of an indigo blue; when formed on an orange coloured field, of a cyan blue; and when formed on a greenish yellow field, of a violet colour.

In the above experiment, you will observe that the greenish blue seen after the eyes have been wearied by long observation of red is the complementary colour to red. In all such cases, the colour seen is the complementary colour either to that which has been observed, or to the colour of the field in which the shadow has been formed. Colours produced in this manner are called subjective colours.

Subjective colours are of considerable importance from the effects they produce when two colours are contrasted or placed alongside each other. When the eye looks at two colours that are placed alongside each other, each will look as if it had been mixed with the complement of the other. Suppose, for example, a red coloured fabric is placed alongside a fabric of a greenish blue colour. Under these circumstances the red will so affect the eye as to make anything at which it is looking appear to possess a greenish blue colour, so that the actual greenish blue will appear of a deeper hue. In the same way looking at the greenish blue colour will fill the eye with a reddish colour and so make the red appear of a deeper red. In this way complementary colours tend to increase one another's brilliancy.

The proper contrast of colours is a matter of great importance in the furnishing of a house, or in the selection of the different colours for articles of dress.

It is by no means an easy matter to be able to see the true colour of an object when it is placed alongside some other colour. I fear that an unprincipled salesman, who has by experience become aware of this curious effect, may sometimes take an unfair advantage of a purchaser who wishes, for example, a carpet of a particular shade of green.

Convinced that he has no carpet of the desired shade of green, under the pretext of resting the eye of his customer, the salesman calls attention to a beautiful shade of red or crimson carpet that he skilfully unrolls on the floor. Then, when his customer's eyes have become so affected by the red that they see green in everything at which they look, he pretends suddenly to remember he has a carpet of the shade of green that is exactly what his customer desires. With the remark: "Oh, I remember now, here is a green carpet I think will just suit you," he unrolls a green carpet alongside the red. Now if the customer saw this green carpet alone, he would never buy it, but the green that is actually in the carpet being mingled with the green in his eyes, there is produced the exact shade of green he desired, so the customer purchases the carpet and has it sent home.

I need hardly say to you that such a carpet would fail to suit, since it will only appear of the shade of green desired when placed alongside a roll of red carpet.

In a similar way, as all ladies know, much difficulty is often experienced in obtaining an exact match for a zephyr or a coloured ribbon. You might explain to such people that, if they wish to obtain an exact match, they must try to come to a decision promptly before the eyes are fatigued. They must, moreover, as far as possible, insist on doing this work away from any other colours, since in this way only can they obtain a satisfactory match.

The effect produced by the contrast of colours is so marked that artists are unable to tell, by merely observing a colour on the palette, how it will look in a painting, since alongside some other colour it no longer appears as it did when alone on the palette.

CHAPTER XVIII

INVISIBLE LIGHT

I AM not certain that the above chapter heading, "invisible light," is correct. Strictly speaking, if by visible light we mean those waves in the universal ether that are capable of directly affecting the eye, we cannot properly call light any waves that are incapable of doing this. Nor would the term invisible rays be any better, since none of the ether waves are visible, unless they pass through the eye and fall on the retina.

If you have followed what I have said regarding the great number of different rays that exist in the solar spectrum between the red and the violet rays, you will agree with me that ordinary sunlight is exceedingly complex, consisting of a great variety of different rays. If, however, we examine this matter still further, it will be seen that we have only commenced to understand how exceedingly great the complexity of sunlight is.

There are three different kinds of rays present in sunlight, and indeed in most luminous bodies; namely, the luminous rays, or those that are capable, when entering the eye, of producing light; the heat rays, or those that are incapable of affecting the eye as light, but when absorbed by matter, are capable of raising its temperature; and the chemical or actinic rays, or those which, while incapable of producing either light or marked heating effects, possess the power of breaking up the combination between chemical substances, or of causing them to unite with one another.

So far as the visible part of the spectrum is concerned, it would, perhaps, be more correct to say that these rays are capable of producing three different kinds of effects; for, in many cases, the same rays are capable of producing all three of these effects; i.e., they can excite the sensation of light when they fall on the retina, or may, when absorbed by ordinary matter, either raise its temperature or exert chemical action on it.

Taking the case of the sun as a type of body that produces white light, let us inquire as to which of its rays possess, to the greatest extent, the power of producing luminous effects. Now I must ask you to remember that none of the rays of the solar spectrum are capable of producing light unless they actually pass through the eye and fall on the retina.

While any of the rays between the red and the violet in an ordinary spectrum can excite the sensation of light; yet the amount of this excitation is least in the case of the violet rays, and is greatest in the rays that are situated in the yellow portions of the spectrum.

Practically, all portions of the solar spectrum between the red and the violet, as well as the portions that lie beyond the violet and below the red, possess the power, when absorbed by ordinary matter, of raising its temperature, and, in so doing, of setting up heat waves in the ether. Heat waves are much longer than light waves, and, therefore, produce relatively so few waves per second that they are incapable of affecting the eye. It is these waves that form what is sometimes called invisible light.

In a similar way, all the so-called visible portions of the spectrum (that is, all the rays between the red and the violet) when absorbed by certain kinds of matter, are also capable of either producing chemical decomposition (that is, of causing a separation to occur of substances that have already entered into chemical combination with each other, or of causing substances that have not yet combined to enter immediately into chemical combination.) Like the heat rays, these rays are not limited to the visible portions of the spectrum, but extend both above or beyond the violet and below the red. They are called the chemical or the actinic rays, and, in the portions of the spectrum beyond the violet and below the red, also form what is sometimes called invisible light.

The effects produced by ether waves depend, therefore, on the kind of matter by which they are absorbed. If, for example, the rays fall on the retina and can excite in it vibrations that are sufficiently rapid, they will produce the sensation of light. If they fall on matter and are absorbed, so that they cause its molecules to move to-and-fro at a less rapid rate, they will produce what are known as heat rays, although these heat rays differ in no respect from light rays save only in the rapidity with which the molecules move to-and-fro, or in the number of waves they produce per second. I shall explain thoroughly to you in "The Wonder Book of Heat" the peculiarities of heat waves.

When, however, ether waves fall on certain kinds of matter and are absorbed, the atoms making up the molecules are set into vibrations so great that they move beyond one another's mutual attractions. The molecules are then broken up, or chemically decomposed, and the atoms may enter into new combinations. In this way, the ether waves produce a force known as the chemical force, or chemical affinity. This, however, is a matter requiring special consideration, and will be fully explained in "The Wonder Book of Chemistry."

Various methods have been employed in order to determine the portions of the solar spectrum that possess the greatest luminous, thermal, and actinic powers. Fig. 76 represents a solar spectrum produced by the passage of a beam of white light through a particular kind of glass known as flint glass. The spectrum is represented at the bottom of the drawing with the rays spread out in different bands from the red to the violet. In this particular spectrum the dispersing power of the prism or prisms employed has been so great that, as you will see, the different portions of the red, orange, yellow, green, blue, indigo, and violet bands have been separated into the different regions marked at the bottom of the spectrum by the letters from A to H.

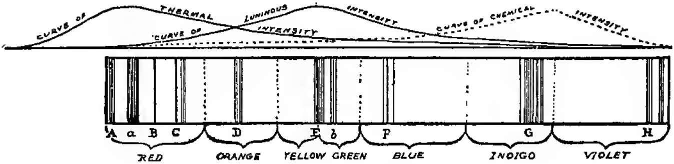


FIG. 76.—THERMAL LUMINOUS AND ACTINIC PORTIONS OF SOLAR SPECTRUM.

It will be observed that three curves, called respectively the curve of luminous intensity, the curve of thermal intensity, and the curve of chemical intensity, have been drawn above the spectrum. The different heights of these curves above the horizontal line represent the relative intensities of the light, heat and chemical action at corresponding portions of the spectrum.

The different heating portions of such spectrum are determined by slowly moving a thermometer through the spectrum not only from the red to the violet, but also in the regions below the red and above the violet; or in the infra-red and the ultra-violet, as these regions are respectively called. In this way, as has been shown by Leslie, the heating power of the rays is least in the violet and gradually increases as the thermometer is moved towards the red until the pale red of the spectrum is reached.

Now while the results obtained in this way are reliable, yet they are reliable only for a solar spectrum that has been produced by the passage of a beam of light through a prism of a certain kind of flint glass, and would not necessarily be true in the case of a spectrum that has been formed by the passage of light through a prism of some other material.

It was Seebeck who was among the first to call attention to the fact that the position of the greatest heating power would vary according to the character of the material that was employed in the construction of the prism. For example, a spectrum formed by the passage of a beam of sunlight through a hollow prism filled with water, has its greatest heating power located not in the red but in the yellow, while, if the same prism is filled with alcohol instead of water, its greatest heating power is found in the orange-yellow.

These differences come about because the materials of which the prisms are made absorb the heat waves, and the measurements only give the portions of the spectrum that have not been absorbed. This necessarily produces erroneous results.

Professor Langley, referring to the difficulty of obtaining the position of the maximum heating or chemical power of a prism, suggests that, in order to avoid the absorption due to the material of the prism, a diffraction spectrum should be employed. This is a spectrum formed by the interference of the rays of light on their passage through, or reflection from, a plate of glass ruled with a great number of parallel lines so close together that many thousands can be crowded side by side in the space of an inch. With such a spectrum the greatest heating rays, instead of being found in a part of the spectrum different from that of the minimum luminous rays, actually agrees with it. Both of these positions are to be seen in the two curves represented in Fig. 77. Here, the full line represents the curve of heat. Its greatest heating power is found not in the infra-red but in the orange or the orange-yellow, which corresponds closely to the dotted curve representing the distribution of the luminosity; for, in the curves represented both in this and in the preceding figure, the values of the heating power and the luminous power, etc., are represented by the height the curve extends above the horizontal line representing the spectrum. A curious thing about the diffraction spectrum is that its curve of heat extends much further below the infra-red than it does above the ultra-violet.

It may be interesting to you to know that in his measurements of the heating power of the spectrum, Prof. Langley employed an electrical apparatus called a bolometer. This instrument depends for its operation on a well-known principle in electricity, in which two wires, connected with a voltaic battery or other electric source, form the two arms of what is known as an electric bridge or balance. When these arms or wires are at exactly the same temperature, the needle of a galvanometer placed in the circuit remains at rest, but if one of the wires or arms is heated only a small fraction of a degree beyond the other, a change at once occurs in the position of the needle.

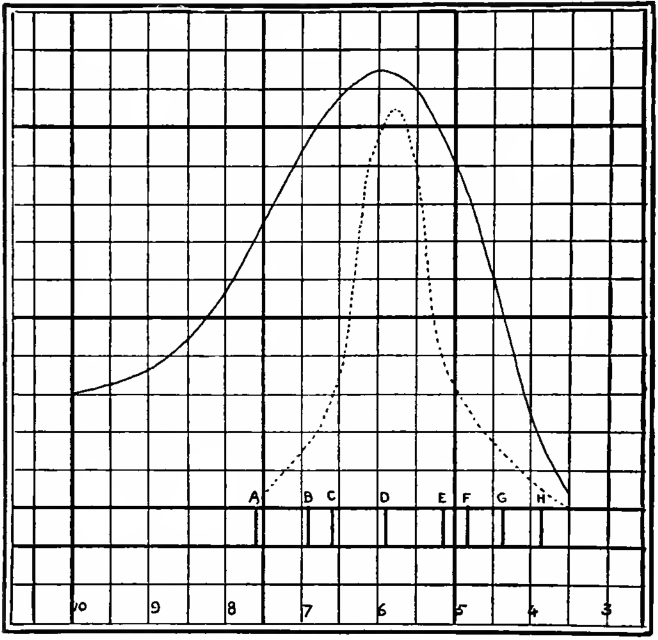


FIG. 77.—DISTRIBUTION OF HEAT AND LIGHT IN DIFFRACTION SPECTRUM.

The bolometer Langley employed was so delicate that it could almost instantly detect a difference of temperature of 0.00001° C. This difference of temperature was produced in a thin strip of metal 1-10000 of an inch in thickness. To give you some idea of the small difference in temperature the instrument could detect, I will give you an illustration used by Professor Langley. While exploring a certain portion of the ultra-violet rays of a diffraction spectrum, Langley was able, after an exposure of less than ten seconds in a certain part of the spectrum, to detect a difference of temperature so small that if the amount of heat causing it had been permitted to fall for over 1000 years on a kilogramme of ice (2.2046 pounds avoirdupois) at the temperature of melting the ice, it would have been insufficient to melt it.

But let us now consider the rays of the spectrum that are capable of causing chemical combination.

If a sheet of white paper, covered with a thin layer of chloride of silver, is exposed to sunlight, a chemical decomposition takes place. The chloride is decomposed and metallic silver, of a dark purplish black colour, is deposited on those portions of the paper that have been exposed.

Another instance of chemical decomposition caused by light occurs on a large scale in nature in the delicate structures of the leaves of plants. The carbonic acid gas of the atmosphere is absorbed or breathed in by the leaves. When sunlight falls on them, nearly all the constituents of the white light, except the greens, are absorbed. It is the absorbed colours that cause the carbon and oxygen atoms in the molecules of carbonic acid gas to vibrate towards and from one another so violently that they are finally carried beyond the distance at which they can mutually hold on to each other. The carbonic acid is, therefore, decomposed, the carbon being retained for the formation of the woody tissues of the plant, and the oxygen thrown off into the air.

The tendency of coloured fabrics to fade or lose their colours, on exposure to sunlight, is due to the chemical decomposition of their colouring matter under the influence of sunlight.

An example of chemical combination being caused by sunlight is seen in the case of a mixture of chlorine and hydrogen gases. This mixture can be kept for a long time without combining, provided light does not fall on it, but will almost instantly enter into an explosive combination under the influence of full sunlight.

The chemical substances employed in photographic operations, some of which will be referred to in a subsequent chapter on photography, are influenced mainly by the light waves that are situated in the neighbourhood of the blue and violet rays of the spectrum. In the green leaves of plants, however, it is the rays in the neighbourhood of the reds, oranges and yellows, forming the absorbed portion of sunlight, that cause the decomposition of the carbonic acid that has been absorbed in the leaves of the plants.

It is evident, then, that there exists in the visible portions of the solar spectrum between the violet and the red, rays that are capable of causing the chemical decomposition of many of the bodies on which they fall. In other words, in addition to being able to produce the effects of light, these rays, when falling on certain kinds of matter, are able to produce either heating or chemical effects.

If a hollow glass prism, filled with the highly refractive and transparent liquid known as bisulphide of carbon, is placed in the path of a beam of sunlight, there will be produced on a screen a beautiful solar spectrum containing not only all the visible rays, between the reds and the violets, but in addition the invisible rays of the ultra-violet and the infra-red. Now mark on the screen the position of the visible spectrum, replace the hollow prism filled with the transparent carbon bisulphide by an exactly similar prism, in which the transparent liquid has been rendered black and opaque by dissolving in it a quantity of a chemical element known as iodine. If a beam of white sunlight is passed through this prism, which, while absolutely opaque to light rays, is quite transparent to the heat rays, there will be formed on the parts of the screen where the coloured bands of light were seen between the red and the violet, a heat spectrum absolutely invisible to the eye, but capable of producing marked heating effects on objects brought into its different portions. If a thermometer or bolometer is moved along different portions of this invisible spectrum, it will show the presence of heat all the way from the ultra-violet to the infra-red, and, indeed, would show an increase in the amount of heat in the regions of the infra-red.

Now the invisible heat rays of the spectrum so formed are capable of being collected at a single point or focus in the same manner as are the visible light rays. If, therefore, the beam of heat rays is permitted to fall on the surface of a concave mirror, or is passed through a double convex lens, the rays will be brought to a point or focus that I am sure you will agree possesses an exceedingly wonderful property. Such a focus is absolutely invisible to the eye. Moreover, the air of that part of the room in which it is situated, may be quite cold, as cold indeed as the air in the rest of the room. So far as one can *see,* this portion of the room possesses no property different from the rest of the room. It does, however, possess astoundingly different properties; for if a piece of lead, zinc, or iron be brought into it, the metal at once becomes so hot that it is melted. If a refractory material (that is, a material that is capable of being raised to a high temperature without melting) is brought into it, the metal is raised to an intense white heat, and becomes a brilliant source of light.

This curious power of obscure or invisible heat to raise the temperature of a refractory body like platinum or iridium to luminosity is called calorescence. Calorescence is a wonderful phenomenon. Indeed, quite as wonderful as any ghost or spectre you could conceive of.

I would caution you not to be so sure that seeing is believing, or, what amounts practically to the same thing, that because you fail to see a thing, you are, therefore, justified in doubting its existence. Suppose I took you into a well-illumined room and cautioned you to be careful how you passed through a certain portion of the air of the room, say some point near the middle of the room, situated about four feet above the floor. Suppose I told you that that part of the room possessed the marvellous power of burning you; that it would instantly make red hot any part of your clothing that might be brought into it. You possibly have so high an opinion of your ability to see things that you turn to me and declare you are surprised I should think you so easy; that you have eyes and know how to use them; that you are sure there is nothing in that part of the room since you can *see* that there is nothing there; that you will convince me I am wrong by deliberately going to that particular part. If you should do this, I, of course, seeing that you did not seriously injure yourself by your folly, should permit you to bring say a portion of your coat or of your pantaloons into the invisible heat focus.

Instantly, you not only *smell* the burning cloth, and *see* a bright glowing spot in the cloth, but you also soon *feel* the intense heat focus, so that, running in terror from this mysterious and awful place, you are ready to admit your foolishness, and to acknowledge that there are things in the room no one can see. You admit you are not justified in believing that a thing does not exist simply because you fail to see it.

But there are still other kinds of invisible rays. If the ultra-violet rays of the spectrum are brought to a focus by reflection from the mirror, or by their passage through a lens, there will also be formed a focus of rays beyond the power of our eyes to see. This focus consists neither of light rays nor of heat rays, but of the chemical rays lying beyond the ultra-violet. If you permit these rays to fall on a sheet of white paper that has been soaked in the chemical substance known as the bisulphate of quinine, the paper will become visible and will emit a peculiar coloured light.

This method of causing the invisible light beyond the violet, or the waves that are too rapid to affect the retina of the eye, to be lowered in the number of their vibrations so as to effect the eyes is known as fluorescence, and will be described in a subsequent chapter.

It would appear, therefore, that there are two species of invisible rays; namely, those in the infra-red that are unable to affect the eye because the waves they produce per second are too few, and those in the ultra-violet that are too rapid to affect the eye. The first can be increased as regards the number of waves or vibrations per second until they can affect the eye by calorescence. The other can be decreased by fluorescence in the number of waves until they are able to affect the eye.

But even the above does not include all the invisible rays that exist in the solar spectrum. In a book entitled, "Waves and Ripples," by Dr. J. A. Fleming, of University College, London, who has devoted considerable time to this matter, there is an account given of the different kinds of ether waves as far as they have yet been studied. In order to show the extent of these waves, they are rated in what are known as octaves, a word taken from music, and meaning the gamut or scale that exists between any two successive notes of the same name, such as *ut* or C, and its eighth higher note or octave; or between a *re* and its octave, and so on. This is a convenient measure, since the higher octave is always produced by exactly twice as many vibrations as the lower note. Now in the case of light, there is, approximately, one octave between the visible parts of the spectrum as contained in the red and the violet; that is, the most rapid visible rays in the violet are produced by about twice as many waves per second as the lowest visible rays in the red.

It has been shown that, in addition to the so-called luminous ether waves between the red and the violet, there are above the violet rays two octaves, and, in addition, a number of shorter ultra-violet rays, and possibly, even beyond these, the so-called ultra-ultra-violet rays which, in the opinion of some, constitute the X-rays.

Then coming down into the region of the infra-red (that is, to the rays that are situated further from the red in a direction away from the violet towards the red) we have seven octaves of dark heat waves.

Then come five octaves of a radiation the character of which is as yet unknown. Still further down in the spectrum, we come to the electro-magnetic waves, the existence of which was first known by Hertz, but predicted on theoretical grounds by Maxwell. Of these, there are at least twelve octaves, and still beyond these are ether waves, a thousand feet or more in wave length, that are employed in wireless telegraphy.

CHAPTER XIX

SPECTRUM ANALYSIS

As you probably know, it is the province of chemistry to determine the composition of a body, either by a process called analysis, or a separation into its different elements; or by a process called synthesis which causes its constituent elements to combine with one another in the proper amounts so as to form the substance. The exact composition may be accurately determined by either of these processes. To make this clearer I will give you an example. Common table salt, when analysed, is found to consist of two elements, a metal called sodium and a greenish yellow gas called chlorine, these two substances being combined chemically in the proportion of one atom of sodium to one atom of chlorine.

The composition of table salt can also be determined by synthesis: If we cause sodium and chlorine to combine, in the proportion of one atom of sodium to one atom of chlorine, we will obtain a substance whose properties in all respects resemble the properties of common table salt. We will, then, again have proved that this substance consists of an atom each of sodium and chlorine chemically combined.

The science of chemistry is now in such an advanced condition that it is a comparatively easy matter to determine the composition of all known substances by analysis, and of many substances by synthesis.

To determine the composition of a substance, it is only necessary to separate a small quantity of the substance into its constituent elements by analysis, and then, where it can be done, to cause these elements to re-combine, so as to produce the substance by synthesis. When you come to study chemistry, you will find but comparatively few cases of substances produced by animal or plant life that can be formed by synthesis.

One of the most wonderful things connected with light is that there is now known a variety of analysis by which the chemical composition of a substance can be determined without the chemist being obliged to obtain a specimen of the substance that is to be analysed. All that is required is to examine the light given off from the substance after it has been raised to a sufficiently high temperature to change it into a vapour and to cause the vapour to glow or become self luminous.

In this kind of analysis it makes no difference how far off the body may be that is being analysed. If its light reaches us, we can determine its chemical composition almost as well as if it were only a few feet distant.

As you know, many of the fixed stars are so far away from the earth that it takes their light, although travelling with the enormous velocity of 186,680 miles per second, hundreds or even thousands of years to reach the earth. It is possible that some of the dim or hazy bodies called nebulæ are even further off. But if we can only obtain a specimen of their light, we can determine the chemical substances that exist in them in the form of glowing vapours, quite as well as if we had specimens of these substances in a laboratory only a few feet distant.

Before explaining how this kind of analysis is possible, I wish you to think the matter over, so as to be sure you appreciate how exceedingly great a wonder it is. Think of bodies that are millions of millions of millions of miles distant being obliged to reveal to the inquisitive physicist exactly what chemical elements are glowing in their atmospheres. It is indeed a great wonder. I remember a jingle that was impressed on my mind in the nursery. I then thought it very beautiful poetry. I feel sure you have heard it, for it forms a portion of the folk-lore that nurses are fond of reciting to their young charges. It runs as follows:

"Twinkle! twinkle! little star,
How I wonder what you are!
Up above the world so high,
Like a diamond in the sky."

As soon as I have explained spectrum analysis to you, such a star no longer possesses any mystery. It may go on twinkling as it has been twinkling for many millions of years. But it can no longer continue twinkling mysteriously, so as to hide its composition. It is only necessary to look at it through a certain piece of optical apparatus and it can instantly be compelled to declare just what kind of glowing or luminous chemical elements it has in its atmosphere.

I am sure it will please you when you learn that the wonderful instrument that can analyse a body many millions of miles distant is no other than the slightly modified magic wand of our acquaintance Prince Percinet.

I think it is almost certain that Prince Percinet knew all about this additional property of his fairy wand. He was such a bright fellow, and did so many other wonderful things that I am disposed to believe he not only knew of this, but even of other properties that we slow mortals have not yet discovered. Indeed, I can picture to myself the possibility that, on a certain night he was walking with Graciosa through the garden in his mother's palace, when Graciosa repeated to him the nursery rhyme: "Twinkle, twinkle, little star," Percinet, turning to Graciosa, remarked:

"There is nothing wonderful about that star, my dear; we fairies know exactly what it is," and then holding his wand so as to look through it from one end to the other he remarked:

"I can distinctly see in the atmosphere of the star glowing masses of hydrogen, sodium, magnesium, calcium iron, bismuth, tellurium, antimony, and mercury."

Of course this was all Greek to Graciosa, but she probably replied:

"Is that so, my dear? How extremely wonderful!"

Of course what Percinet saw when he looked through his magic wand, that is, through a prism, was something peculiar about the appearance of the spectrum of the star; that is, the stellar spectrum. It is possible in the same way to determine the composition of the sun by the appearance of the spectrum of sunlight.

This method of analysing a substance, or of determining its chemical composition from the peculiarities of the spectrum of the light it emits, when in the form of a glowing vapour, is known as spectrum analysis. Let us, therefore, endeavour to understand the principles on which this peculiar kind of analysis depends.

Spectrum analysis depends on the fact that if the rays of light, coming from a vapourised luminous body, are examined through a prism, the composition of the body can be determined by the peculiar character of its light. A pure yellow light, as we have seen, can readily be obtained by placing a small quantity of common salt in the colourless flame of a Bunsen burner. The peculiar colour of this light is due to the presence of highly heated or glowing particles of a volatile sodium salt. In the same way a volatile salt of copper imparts a deep green tint to the light of a Bunsen burner owing to the glowing particles of the copper salt. Zinc imparts a purplish colour to the flame, and the metal strontium a deep crimson colour.

Now when the light, given off from glowing sodium salt, is passed through a prism, instead of producing a continuous spectrum or band of different colours from the red to the violet, it produces only a few bands of orange and yellow light that are separated from each other by dark spaces. In other words, the incandescent vapour of the sodium salt is capable of giving off only a few different rays in the neighbourhood of the orange-yellow part of the spectrum. Its spectrum, therefore, consists of these colours only; all the other regions are absolutely dark.

In a similar manner, the light given off by the vapour of zinc consists of a few brilliant purplish bands; that is, glowing zinc vapour can throw off purplish light and purplish light only. In a similar manner the light produced by the glowing copper salt gives a series of green bands only.

The possibility of determining the composition of a substance that exists in the form of an incandescent or glowing vapour depends on the fact that the light the substance then throws off is characteristic of that particular element only. The glowing vapours of no two different elements in the universe give off light of the same wave length or colour. Glowing sodium vapour emits a light characterised by the peculiar orange-yellow bands before referred to; and the glowing vapour of no other substance is capable of giving off the same kinds of light. Glowing zinc vapours give off a purplish coloured light that is unlike the light emitted by the glowing vapour of any other chemical substance, and the same is true of all the known chemical substances.

The eye is unable to pick out the different coloured rays present in the lights given off from different glowing substances. It is, however, an easy matter to examine such light through a prism, and thus at once determine the name of the chemical substance from the peculiarity of its light.

There are a fairly great number of different chemical elements that produce more than a single coloured ray. You can see, therefore, that it must have taken long and patient study on the part of scientific men to determine the peculiarities of the spectra produced by each of the different chemical elements when in a state of incandescent or glowing vapour.

I would say here that if any substance, no matter what its chemical composition may be, is raised to intense incandescence while in the solid or liquid state, it will become white hot; that is, will emit a light that would produce a continual spectrum, or a spectrum in which all the different coloured rays are present from the red to the violet. It is impossible, therefore, to analyse an elementary substance, or to determine its chemical composition, by examining its light when heated to incandescence in a solid or a liquid condition. In order that the substance may give off a characteristic light, it is necessary that its molecules and atoms shall possess the freedom of motion they have only when in the condition of a vapour, and that, moreover, this vapour be highly heated, so that not only its molecules, but also the atoms within the molecules, are made to move violently to-and-fro, and thus produce characteristic waves in the ether surrounding them.

It was Prof. Bunsen, the great German chemist, and Prof. Kirchhoff, the equally great German physicist, who, while examining the light given off from certain glowing materials, detected the presence of peculiar spectra that were produced by no known substances on the earth. They, therefore, properly came to the conclusion that what they saw was the spectra of two hitherto undiscovered chemical elements. After making an extended chemical investigation, they proved that this inference was correct by isolating the then new chemical elements, rubidium and caesium.

It was in a similar manner that the English physicist Crookes discovered the existence of the new element thallium.

As in the case of many other wonders of the physical universe, the wonder of spectrum analysis, although at first sight seemingly beyond the powers of the human mind to comprehend, becomes ridiculously simple as soon as explained. You can see how easy it should be to determine the composition of a chemical substance from an examination of its spectrum, if it can be shown that every chemical element, when in the condition of a glowing vapour, gives off light that is characteristic of that element only. As soon as this fact is appreciated, the wonder completely disappears.

There are, however, some phenomena connected with spectroscopic analysis that are more difficult thoroughly to understand.

The rays of the solar spectrum lying between the red and the violet possess the power of causing not only the sensation of light, but also, as we have seen, when absorbed while passing through different kinds of matter, of causing heat.

Certain substances are quite transparent to the ether waves; these waves can pass through them, between their molecules, without imparting any motion to the molecules, that is, without heating them. There are other substances, however, so opaque to ether waves that when these waves endeavour to pass through them they are absorbed or quenched; and, if they were originally luminous, they are no longer able to produce the sensation of light, but are changed into heat waves.

Now the light given off by any glowing incandescent vapour is absolutely opaque to light of the same wave length as its own. The glowing sodium vapour, in the flame of the Bunsen burner, that emits orange-yellow light only, is perfectly transparent to all the other coloured rays, permitting them to pass without absorption. But when rays of the same orange-yellow light attempt to pass through, they are completely stopped. The orange-yellow light of glowing sodium vapour is opaque to light of the same wave length as its own, and this is true of the green light given off by glowing copper vapour; of the purplish light of glowing zinc vapour; of the reddish or crimson light of glowing strontium vapour, etc.

An interesting discovery that at first gave scientists considerable trouble has been made concerning the solar spectrum. In order to be able to examine this peculiarity of the spectrum it is necessary that the instrument employed be what is called a pure spectrum. When a beam of light passing through a slot or opening in the shutter of a darkened room is permitted to form a solar spectrum, unless the slot is very narrow, the spectrum will consist of a series of separate bands of colour overlapping one another. If we wish to examine all the peculiarities of a solar spectrum it is necessary not only that the opening in the shutter shall be exceedingly narrow, but also that the beam of light shall have its separate colours dispersed as far from one another as possible, so that the separate bands shall not overlap, but lie side by side.

In order to ensure a marked dispersion of the different rays, it is necessary to employ more than a single prism, and to permit the beam of light to pass successively through the separate prisms. A narrow slice of light passed successively through nine separate prisms causes a great dispersion or separation of the different coloured rays.

When great care has been taken to obtain a pure solar spectrum, so that the successive images of the slot do not overlap, and, moreover, when a spectrum has been obtained in which different rays of light are widely separated by dispersion, it is found that the coloured bands lying between the red and the violet are not continuous. In certain portions of the spectrum, some of these bands are missing, and their places are occupied by numerous dark lines. This peculiarity of the solar spectrum was first observed by Dr. Wollaston, the celebrated English physicist. It was afterwards studied with unusual care by Dr. Fraunhofer, who carefully observed and mapped out the various dark lines, marking their position by the letters, A, a, B, C, D, E, b, F, G, and H. The approximate position of these lines in the solar spectrum is represented in Fig. 76 (page 206.) These lines are called the Fraunhofer lines in honour, not of their discoverer, for that was Wollaston, but of the man who by careful and patient study showed how they could be employed.

The cause of the Fraunhofer lines gave physicists considerable trouble. The problem, however, was at last solved by Fraunhofer, who gave so complete an explanation of these lines that it became possible to ascertain the chemical composition of a body like the sun, even though its central mass gave a conscious spectrum, provided only it had glowing vapours in its atmosphere.

The Fraunhofer lines are caused as follows: As we have seen, a glowing vapour is opaque to light of the same colour it is itself emitting. The orange-yellow light emitted by glowing sodium vapour is opaque to light of the same colour, but perfectly transparent to light of all other colours. If, therefore, a beam of white light is sent through a mass of glowing sodium vapour, all its coloured rays except a few orange and yellow rays, will be able to pass. These few orange-yellow rays, however, will be completely stopped. If the spectrum of a beam of the white light obtained from an electric arc lamp is thrown on a screen, it will produce a continuous band of colour from the red to the violet. If, now, before it is permitted to pass through the prism, this light is caused to pass through a mass of glowing sodium vapour, a few orange and yellow rays will be absorbed, so that, instead of a continuous spectrum being thrown on the screen, dark bands will be seen occupying the position of the few orange-yellow rays that have been absorbed. If, instead of sodium vapour, a mass of glowing zinc vapour is introduced into the path of the beam, certain rays of purplish light will be absorbed and dark bands will be seen in the part of the spectrum formerly occupied by this light; and the same is true for the greenish light produced by glowing copper vapour as well as by the peculiar light produced by any other glowing vapour.

If, therefore, the sun, which as we know emits a continuous spectrum from the red to the violet, should have in its atmosphere glowing masses of vapours of the different chemical elements, as must exist by reason of its high temperature, these vapours, being opaque to the particular coloured lights they are emitting, prevent the passage of these particular rays from the sun, so that its spectrum, instead of being continuous, is characterised by a series of dark lines. These are the Fraunhofer lines.

If you consider the matter sufficiently you will see that the Fraunhofer lines do not mark positions of absolute darkness, since these lines are, in reality, illumined by the light given off from the glowing vapours in the sun's atmosphere. But since their light is feeble when compared with the light given off by the sun itself, they appear dark by contrast.

It will certainly interest you to know that when analysed in this manner, the distant star Aldebaron is found to have in its atmosphere glowing masses of hydrogen, sodium, magnesium, calcium, iron, bismuth, tellurium, antimony, and mercury, and that the star Alpha, in the great constellation of Orion, has in its glowing atmosphere, sodium, magnesium, calcium, iron, and bismuth.

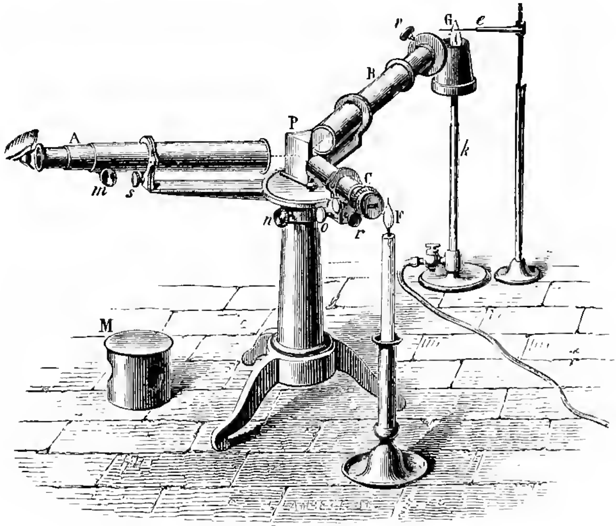


Fig. 78.—A Spectroscope.

When the distant nebulæ are examined in the same way, it is seen that they consist of masses of highly heated gaseous matter in most cases the elementary gases hydrogen and nitrogen.

Much study has been given to the solar spectrum and to the mapping or locating of the Fraunhofer lines. Fraunhofer counted 600 of these dark lines in the solar spectrum; Brewster mapped out 2,000 of them, while more recently over 3,000 have been accurately located. By passing the light successively through a number of prisms, many of the lines that were apparently single have been shown to consist of two or more lines.

The apparatus by means of which spectroscopic analysis is rendered possible is known as the spectroscope. This apparatus consists, as shown in Fig. 78, of three telescopes A, B, and C, mounted on a common stand, pointing as shown towards a prism P, of flint glass. The telescope A is arranged so as to be turned around the prism, and, when placed in the position desired, can be firmly clamped by means of the clamp screw *n*. A screw *m* is provided for the purpose of obtaining a sharp image of the spectrum by the focusing of an eye-piece.

The use of the two telescopes B and C, will be understood from an examination of Fig. 79. The substance that is being examined is placed in the flame G. The light its glowing vapour emits, passing through the lens *a*, is converged to a focus *b*, so that, when it passes through the lens *c*, it leaves the telescope B as a beam of parallel rays. These rays, after passing through the prism P, in which they are dispersed, enter the lens *x* placed at one end of the telescope A, and form an inverted image of the spectrum at *i*, which when viewed by the observer, is seen as a magnified image eight times as large as the image the eye-piece is examining.

The telescope C is provided for the purpose of measuring the relative distance the different lines of the spectrum are apart.

It may be interesting here, before leaving the subject of spectroscopic analysis, to call your attention to the fact that in the above descriptions we have referred to three different kinds of spectra; namely:

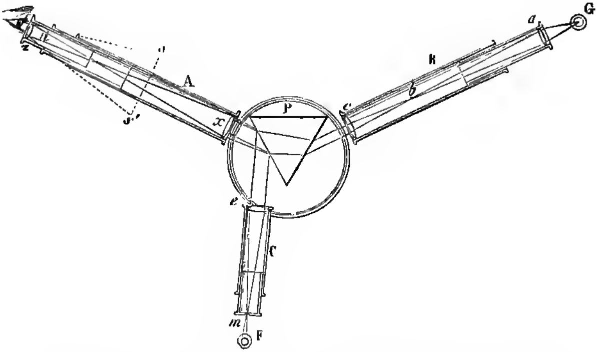


FIG. 79.—PASSAGE OF LIGHT THROUGH SPECTROSCOPE.

(1). Continuous spectra, or those produced by solids or liquids heated to incandescence.

(2). Band or line spectra, or those produced by glowing masses of incandescent vapour. These spectra are discontinuous and consist of light of a few wave lengths only.

(3). Absorption spectra due, as are the dark Fraunhofer lines, to the absorption of the light of an otherwise continuous spectrum by the glowing masses of vapour that are opaque to the particular coloured light they are emitting.

CHAPTER XX

DISEASES OR ABERRATIONS OF LENSES

Now that we have not only studied the peculiarities of the different foci of lenses, but have also learned about the different coloured rays that exist in sunlight, I can keep my promise to tell you something about the failure of lenses properly to reproduce in their images the correct outlines and colours of the objects placed before them. These difficulties are known as the aberrations of lenses.

As you probably know, the word aberration means a wandering or departure, and is applied to a lens to indicate an effect different from what the lens would produce if it were working properly, or were in what might be called by some flight of the imagination, a healthy condition.

Speaking now of lenses only, for some of these troubles are found in mirrors also, I will say that a lens possesses three different kinds of wanderings or aberrations, any one of which will prevent the image it produces from closely resembling the object. Since the word aberration is difficult to remember, I have taken the liberty of regarding as unhealthy or diseased, those lenses which fail to produce the images that normal healthy lenses should produce. In this sense we should use the word diseases as correctly expressing or meaning aberrations.

Double convex lenses are especially apt to possess diseases in the outlines of their images. Instead of forming a single image of sharp and correct outlines, they are apt, under certain circumstances, to produce a number of separate images that are spread at different distances from the lens along a line called the principal axis of the lens; i. e., a straight line passing through the centres of the opposite faces of the lens. This aberration makes it impossible to obtain a distinct image of the object. Another kind of aberration causes the straight lines in objects to appear as curved lines in the images, while curved lines in the objects are incorrectly reproduced, and the image is again indistinct. Let me try to explain to you the causes of these two different kinds of lens diseases.

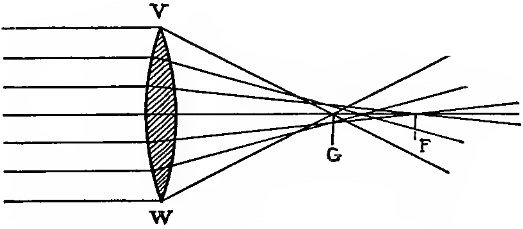


FIG. 80.—ONE OF THE DISEASES OF LENSES.

When a double convex lens has a width that is large in comparison with the amount of the curvature of its opposite faces, its images, as represented in Fig. 80, will possess an aberration of the first character, so that a number of images will be formed along the principal axis. As you have already seen, a well-formed double convex lens should bring parallel rays of light to a single focus on the opposite side of the lens known as the principal focus. Now when the lens is too greatly swelled, or puffed out, at its opposite faces in proportion to its width; or, in other words, when its opposite faces are too greatly bulged, parallel rays of light will not be brought to a single focus F, but, as shown in the above figure, to a number of separate foci between F and G; for the rays of light falling at the edges V and W, of the lens, are brought to a focus at G that lies nearer to the lens than the principal focus F; while the rays falling near the middle of the lens are brought to a focus at F, and rays intermediate between these points are brought to different foci between F and G. This character of aberration is known as longitudinal spherical aberration. This long phrase only means that the images wander out of place in the direction of a straight line, because the lens has its opposite faces too much curved or swelled.

The other disease of double convex lenses is that in which the straight lines of its images are curved and the curved lines improperly curved. This disease is also caused by the too great curvature of the lens; that is, by the lens being too greatly swelled, curved or puffed out at its opposite faces. When an object possessing straight lines is placed before such a lens, if the images of its extremities are formed at the same distance from the centre, the lines of the image will not be straight, but will be curved. Since, however, the further an object is from a convex lens, the nearer its foci will be to the other side of the lens, the curvature is even more pronounced.

If, in order to avoid either of these false shapes the image is sharply focused, say on a plate of ground glass, so that the central portions shall be as correct in outlines as possible, the distortions at the edges will be greatly magnified. If, on the other hand, an effort is made to focus the extremities of the object, the outlines of the central part will be very irregular. This aberration is known as the aberration of sphericity, and is only another way of saying that the error is due to its central portions being too much puffed or swelled out.

Either of these two kinds of aberrations of lenses seriously interferes with the proper operation of such optical instruments as the telescope, the microscope, and especially the photographic camera.

You can understand how serious a defect would be produced in a photograph of a person's face if a too spherical or bulged image-forming lens should be employed in the camera. Such a lens would perhaps form an image of a person's face with the line of the mouth improperly curved, or an extra crook on the nose, with the eyes and ears even a small fraction of an inch out of place. It would produce, indeed, a dreadful effect. A photographer who would offer his customers such a photograph would certainly be unable to build up a trade, nor could he succeed in making his customers believe, as I understand is sometimes done, that a photographic camera cannot lie. On the contrary, if its image-forming lens is diseased, such a camera is less to be believed than either Ananias or his wife Sapphira.

Since both of the above errors are most marked in the cases of lenses that are too greatly swelled on their opposite faces, instead of trying to remember what these kinds of aberrations are called—namely, longitudinal spherical aberration, and the aberration of sphericity—I will be satisfied if you simply remember what they are and how they are caused; namely, by the opposite faces of the lens being too greatly puffed out or swollen. If you should have any difficulty in remembering this, I would suggest that you might find a resemblance between this particular kind of diseases in lenses, and a disease that I fear is not entirely absent at times in young people, and which indeed, I am free to confess, is sometimes present in older people. I refer to a disease or defect correctly characterised by that somewhat vulgar term, "a swollen head." As you well know, such a diseased head leads its possessor to form too high an estimate of his or her ability to observe or sit in judgment on something they are contemplating. They are unable to form a proper mental image of it, and, therefore, like a diseased lens, are apt to incorrectly describe its nicer or finer details.

But there is another kind of aberration or disease of lenses that is often far more serious than either of the above. This is the kind known as chromatic aberration. It results in the formation of images that fail to possess the colours of the objects. Let us, therefore, carefully look into this form of lens disease.

When a ray of daylight, or ordinary white sunlight, passes through a lens it is not only bent out of its course or refracted, but is also dispersed or separated into its different coloured rays. For example, rays of light that have passed through the extremities of a double convex lens, instead of collecting at a single focus on the other side of the lens, are separated into different coloured rays just as they would be in passing through a prism. Now, since the different coloured rays possess different refrangibilities, the violet rays being much more refrangible than the red, these rays must collect at different foci. If, therefore, rays of light coming from the illumined object pass through the edges of a convex lens, instead of forming a single image of the object they will tend to form a number of separate coloured images that occupy different positions between the violet and the red.

The presence of chromatic aberration in lenses was first observed by Newton when he was studying refracting telescopes. The telescopic images presented coloured fringes at their edges. Newton endeavoured so to improve the construction of his lenses as to avoid this difficulty and after many efforts came to the conclusion that the difficulty arose from the light itself and not from the lens. Under the belief that the dispersive power of a lens was proportional to its refractive power, or, in other words, that if a lens formed of one kind of glass possessed a greater dispersive power than another, it would, at the same time possess a correspondingly greater refractive power, he concluded that he could never hope to be able to construct a lens free from chromatic aberration; or, as such lens is now called, an achromatic lens.

In one of the other Wonder Books I had occasion to call your attention to the fact that scientific men generally possess an advantage over men of the law, in that they care very little for what is called a precedent, a thing that is so highly believed in by gentlemen of the legal profession. I regret to say, however, that so far as the production of an achromatic lens was concerned, scientific men were very much at fault, since they permitted the authority of Newton to stand in the way of an attempt to produce this device. Fortunately, after the world waited some eighty years, a practical optician, John Dollond, came to the conclusion that he would test the correctness of Newton's conclusions. He did so and found them to be erroneous; for he found that the dispersive and the refractive powers were not directly proportional to each other in different media. The result was that Dollond was soon able to produce an achromatic lens.

Both Newton and Dollond saw that if two prisms were placed with their refracting angles opposed to each other, whatever one prism did in separating the rays, the other prism would do in the opposite direction, and so bring the rays all together again, and thus permit them to emerge free from false colouration.

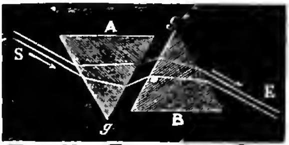


FIG. 81.—EQUAL AND OPPOSITE REFRACTION AND DISPERSION.

If, for example, as represented in Fig. 81, two prisms A and B, be placed with their refracting angles *g* and *g′*, opposed, then a beam of light S, would be dispersed or separated into its prismatic colors while passing through the prism A. If, however, the second prism B, possess the same dispersive powers, then all these colours will be brought together again, so that the beam would pass out from the prism B, as white or uncoloured light.

Now if, as Newton believed, the prism B must have its refracting angle *g′* of the same value as the refracting angle *g*, of the prism A, then the medium AB, would have parallel sides, the beam would emerge parallel to its original direction, and therefore would not be a prism.

When, however, it was found that some media possess twice the dispersive powers of others, the matter assumed an entirely different appearance. For example, flint glass possesses twice the dispersive power of crown glass. If, therefore, a prism of flint glass B, Fig. 82, has one of its sides cemented, as shown, to a prism A of crown glass, and with refracting angle *b* twice as great as *a*, it would form an achromatic prism; for, although a ray of light passing through A would undergo dispersion it would, after passing through B, have its rays dispersed equally in the opposite direction, and thus be free from false colour, yet it would also be refracted; or, in other words, as already stated, the combination would form an achromatic prism.

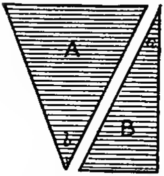


Fig. 82.—Principle of Achromatism.

The manner in which this principle is applied to the construction of an achromatic lens is shown in Fig. 83, where a double convex lens B of crown glass is cemented to a lens of flint glass A shaped as shown. In this combination the dispersive powers of the two kinds of glass completely neutralise each other, but not their refractive powers, so that the combination forms an achromatic lens.

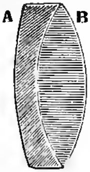


Fig. 83. Achromatic Lens.

But there is another advantage possessed by achromatic lenses. Herschel has shown that an achromatic lens formed of flint and crown glass, shaped and arranged as shown in the preceding figure, is not only capable of forming an image free from prismatic colours, but also one that is nearly free from spherical aberration.

Achromatic lenses, suitable for use in telescopes, are very unsatisfactory in microscopes. It is difficult to construct achromatic lenses sufficiently small for the high magnifying powers required in a microscope. In order to overcome these difficulties it has been found that the best results for use in microscopes are obtained by the use of a number of separate achromatic lenses.

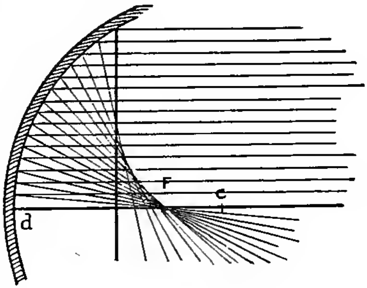


Fig. 84.—Caustic Curve, a common Disease of Mirrors.

Like lenses, mirrors also suffer from aberrations. When a concave mirror is formed by too great a section of a sphere, parallel rays of light, instead of being brought to a single point or focus, are brought to differently situated foci as represented in Fig. 84, in which, as will be seen, the rays falling at the edges of the mirror are brought to foci nearer the mirror than those reflected from near its central portions. Instead, therefore, of a single focus being formed, there are a number of different foci by the intersection of which a brilliant curve of light known as a caustic curve is produced.

CHAPTER XXI

FLUORESCENCE AND PHOSPHORESCENCE

IF the invisible violet rays of the solar spectrum are brought to a focus either by a lens, or a concave mirror, and this focus is caused to fall on certain substances, such as a solution of bisulphate of quinine, the ether waves are slowed down, so as to produce a beautiful bluish light. This effect, known as fluorescence, was first carefully studied by Stokes.

There are various substances that possess this power of so slowing down the ultra-violet rays of light as to permit them to affect the eye. When the bark of the common horse-chestnut tree is boiled in water, the clear solution is invisible in ordinary light, but gives out a bluish light when brought into the ultra-violet rays of the spectrum. The simplest way to obtain this light is to permit the spectrum of sunlight, or of an electric light, to fall on a sheet of white paper soaked in the horse-chestnut solution. The length of the spectrum is then greatly increased; for, instead of being visible only between the red and the violet, it now extends far beyond the violet.

The light of the carbon voltaic arc produces a much greater quantity of the ultra-violet rays than the light of the sun. Prisms formed of clear quartz crystals are almost completely transparent to ultra-violet rays, and differ, in this respect, from prisms made of ordinary glass that are opaque to a large percentage of the ultra-violet rays. If a beam of light from an electric arc lamp is caused to pass through a quartz prism, the length of the ultra-violet spectrum will be from six to eight times longer than the distance between the red and the violet rays. If such a spectrum is received on a sheet of paper moistened with the water, in which the bark of the horse-chestnut tree has been boiled, the length of the visible spectrum will be considerably increased. A space beyond the violet of from six to eight times the distance between the red and the violet rays, will now shine with fluorescent light.

You have all probably seen the greenish coloured glass, known as uranium glass, the colour of which is due to the presence of a small quantity of a chemical substance containing uranium. This glass possesses the power of fluorescence in a high degree, so that if, by means of a lens, a pencil of the ultra-violet rays is thrown within its mass, the path of the rays becomes visible as a bright green light; for the rays as they pass through the glass become luminous by fluorescence.

Some of the many other substances that also possess the power of fluorescence are the green colouring matter of leaves, obtained by soaking bruised leaves in alcohol; ordinary petroleum, or coal oil; a solution of turmeric in alcohol; various kinds of fluorspar, etc. It may be interesting to know that the word fluorescence has been given to this peculiar property of light because its effects were first observed in fluorspar.

If a fluorescent substance is exposed in a darkened room to light from different sources, a difference will be observed in the intensity of the fluorescent light produced. While ordinary sunlight possesses this power in a fairly marked degree, it is surpassed either by the light of the electric arc lamp, or by the light emitted by a burning magnesium wire. The reason is obvious. It is the ultra-violet rays that produce the fluorescence, and the light emitted by the burning magnesium wire on the electric arc, contains a greater proportion of the ultra-violet rays than does sunlight.

The following curious experiment can be made as regards fluorescence. If stramonium, Jamestown or jimson weed, is soaked in water, an almost colourless solution will be obtained. Writing, traced on a sheet of white paper by means of a pen dipped in this solution, will be almost invisible, but if the light from burning sulphur, or brimstone, is permitted to fall on it, it instantly becomes visible by fluorescence. In making this experiment care must be taken not to leave the solution of stramonium where it might be drunk in mistake for water; for it is very poisonous.

The light emitted by the aurora borealis is especially rich in the ultra-violet rays.

Some substances possess the power of fluorescence in a high degree. Two of the most remarkable fluorescent substances are the platino-cyanide of barium, and the tungstate of calcium. These substances are employed for covering the screen in an apparatus known as the fluoroscope that will be described in the next chapter on the X-rays.

It has been known from early times that a substance called Bologna phosphorus possesses the curious property, after exposure to light, of continuing for many hours to emit, in the dark, a pale light. Bologna phosphorus was prepared by heating to incandescence certain minerals and afterwards reducing them to a fine powder. In later years the same kind of material is employed in the production of what are called luminous paints, or paints consisting of various mixtures of sulphur with calcium or barium, that have been calcined and afterwards finely ground.

You have probably seen luminous paints applied to the surfaces of the match boxes that are permanently fixed on the walls of a room. During their exposure to the light in the daytime, these paints are so affected that they will continue to shine during the greater part of the night, although there is no other light in the room. One coming into the room can, therefore, readily see where the match box is.

I have sometimes thought, while searching in a darkened room for a match box, with the danger, before finding it, of overturning bits of china on the mantel-piece or tables, how convenient it would be if such things had voices, so that while you were blundering around looking for them they could call out:

"Don't look there; don't you see me. Here I am." And this is practically just what the luminous paint does. When you go into a room, you have only to listen carefully with your eyes, to hear it calling to you from where it has been placed.

Another practical application of luminous paint is its use over the surface of a clock dial. On waking at nights you can tell the time by looking at the clock dial. There is no need of getting up to strike a light. I would say, however, that in all those cases the light produced in this manner by phosphorescence is exceedingly feeble.

There are many substances that, like Bologna phosphorus and luminous paints, possess, to a greater or less degree, the power of continuing to shine after exposure to the light. Some of these, as in the case of the luminous paints, continue to throw out light for many hours after daylight ceases to fall on them. Others continue to shine for a few moments only. The following substances possess phosphorescence in varying degrees; i. e., the sulphides of barium and calcium, diamonds, a variety of fluorspar known as chlorophane, dry paper, silk, sugar, salts of the alkalies and alkaline earth, compounds of uranium, etc., etc.

Phosphorescence can be produced by exposure to all portions of the spectrum; not only to the ultra-violet rays, but also to all the colours between the reds and the violets, and even to the invisible or heat rays in the infra-red, far below the red itself. In this respect phosphorescence differs markedly from fluorescence, which, as we have seen, is excited only by the ultra-violet rays. If you will think a moment you will understand how wonderful this is. When the ultra-violet rays produce phosphorescent light their too rapid wave motion has been slowed down until it can affect the eyes as light, while in the case of the invisible rays below the red, the too slow vibrations or ether waves have been increased or accelerated until they have become sufficiently rapid to affect the eye.

You can easily try a wonderful experiment in phosphorescence. Heat a dull iron plate in a darkened room by permitting the flame of a Bunsen burner to fall directly on its lower surface. Be careful that the heating of the plate is not carried sufficiently far to render it incandescent. Now, fixing your eyes on the upper surface of the plate, in such a position as to prevent your seeing the flame of the Bunsen burner, throw a few fragments of a variety of fluorspar known as chlorophane on the upper surface of the plate. Instantly a brilliant emerald-green phosphorescent light will be thrown out from the fragments. This light has been produced by the increase in the rapidity of the heat waves from the iron plate to such an extent as to enable them to affect the eyes.

This increase in the rapidity of vibrations of the fluorspar is so difficult to understand that, in the opinion of some, the light so caused by heat is believed not to be due to an increase in the rapidity of the heat waves, but to a liberation of light energy, which, in some way that is not exactly understood, has been charged on the fluorspar during its exposure to light. The name chlorophane has been given to this variety of fluorspar from two Greek words meaning "shining with a greenish light."

A great variety of differently coloured lights are produced by phosphorescence. These different colours are thus described by Professor Rood in his "Text Book of Colour":

"If tubes filled with the sulphides of barium, strontium, calcium, etc., be placed in a dark room and illuminated for an instant by a beam of sunlight, by the electric light, or by burning magnesium wire, they will display a charming set of tints for some minutes afterwards. Some will shine with a soft violet light, and others will display orange and yellow colours. Delicate blues will mark the appearance of others and will contrast well with the red hues, the latter resembling in the darkness living coals of fire."

Much yet remains to be explained concerning many of the phenomena of phosphorescence. Becquerel, the well-known French physicist, made a series of extended experiments and observations of these phenomena and has described them in a large volume. These investigations show that phosphorescence is capable of being excited in other ways than by mere exposure of different substances to light. As we have already stated, the exposure of chlorophane to increased temperature results in the production of phosphorescent light. The same thing is true of some varieties of diamonds.

Then there is a large class of substances, produced either in the living bodies of animals and plants, or formed during the decomposition of their tissues, that possess in a marked degree the power of producing phosphorescent light. The effects of such phosphorescent substances are seen in the light of fireflies and glowworms, as well as in the pale light given off by the water of the ocean when it is ruffled by the wind and looks as though it were all aflame. The light which makes it look this way is due to the phosphorescence caused by various zoophytes, jelly-fish, etc. Here, however, the light only appears when the substance undergoes a gradual burning or oxidation by contact with the air, so that this variety of phosphorescent light is only seen on the ocean when the air has an opportunity of coming in contact with this substance where the surface of the water is ruffled by the wind. This variety of phosphorescence is known as chemical phosphorescence.

But the above are not the only ways in which phosphorescent light can be produced. If crystals of quartz are rubbed together in a dark room, phosphorescent light will appear. It is also produced when lumps of loaf sugar are broken in the dark. Phosphorescent light is also momentarily seen when a solution of certain salts suddenly crystallises in the dark.

From what I have said about the phenomena of phosphorescence I think you will agree with me that they can be regarded as among the greatest wonders of light,.

CHAPTER XXII

X-RAYS AND RADIO-ACTIVITY

ALTHOUGH the subject of both X-rays and radio-activity properly belong to electricity, and will, therefore, be fully treated in that Wonder Book, yet they are so closely allied with light that a short description of each will be given here.

In 1895, a discovery was made in Bavaria by Professor Roentgen, that, by reason of its wonderful nature, caused great excitement in the scientific world. Roentgen was making experiments in a darkened room with some Crookes' tubes, a name given to the high-vacuum tubes we have referred to in the chapter on the light mill.

In a Crookes' tube, electric spark discharges are passed through the traces of gaseous atmospheres left in the tube after as high a vacuum as possible has been obtained. The discharges are passed through the tube by means of platinum wires fused into the glass at its opposite ends, so as to make air-tight joints. As the discharges pass, the space inside the tube becomes luminous, especially where the moving molecules of the residual gas strike its sides.

Wishing to prevent this light from entering the darkened room in which he was experimenting, Prof. Roentgen had covered the tubes with thick pasteboard, blackened so as to prevent any leakage of the light. Believing that no light could possibly pass out of the tube, you may under-

An X-Ray Photograph

From Atkinson's "Electricity for Everybody," published by The Century Co.

stand how surprised he was to see that a sheet of paper covered with a highly fluorescent substance commenced to shine brilliantly.

Roentgen was greatly puzzled. He thought he had made the covering light-tight, but there was the paper shining with a fluorescent light. Some light must have leaked out. He therefore again examined the Crookes' tubes to find where the openings were. Being unable to find any he came to the conclusion that there had been produced in the tube a peculiar kind of radiation that could readily pass through a thick sheet of thoroughly blackened pasteboard. Astonished by the oddness of this discovery, he made many researches, and found that there had been produced in the tube a new kind of radiation possessing the power of readily passing through a great variety of substances opaque to any of the forms of light that he knew could produce fluorescence. Moreover, to his great surprise, this radiation was not only able to produce fluorescence after it had passed through opaque substances, but was also able, like ordinary light, to decompose chemical substances employed in photography. In other words, the new kind of radiation, besides producing fluorescence, could also produce photographic pictures.

It was a great discovery. It seemed as if a new kind of light had been discovered that differed from ordinary light in being able readily to pass through many opaque substances, but which resembled ordinary light in its ability to produce fluorescence and photographic effects. Not knowing the exact nature of the new rays, Roentgen called them X-rays. As you who study algebra will understand, the letter X is frequently used to represent an unknown quantity. The name X-rays Roentgen proposed for these rays meant the unknown rays, and this happy name is still generally retained, although they are sometimes called Roentgen rays.

These rays possess the wonderful power of penetrating substances opaque to ordinary light. The sheets of paper on which this Wonder Book of Light is printed are not very transparent, especially where they are covered with the printer's ink, and yet, if you take this book with its covers and hold it in the path of the X-rays, they can pass readily through it and cause a paper covered with a fluorescent substance to shine brightly. Indeed, if two such books be placed together in the path of the X-rays they could still pass through them and be able to excite fluorescence. In the same way, the X-rays will readily pass through a pack of ordinary playing cards. Indeed, even after the X-rays have gone through two packs, they are still capable of producing the fluorescent effects as well as the photographic effects.

But sheets of paper or pasteboard are not the only kind of substances that are transparent to X-rays. Blocks of wood are also quite transparent to them. Since, when X-rays fall on sensitive photographic plates they produce the same effects as would ordinary light, it is necessary to keep such plates out of the room in which the X-rays are being produced, as they would otherwise be spoiled. There would be no use in placing the photographic plates in drawers; for the X-rays could easily pass through the inch or so of wood at the top or bottom of the table. Nor would it help to wrap the plates up in black paper since they could with equal ease be ruined by the X-rays. If, however, they are wrapped in sheets of thick lead which is opaque to the X-rays, they would be preserved.

I will not stop now to name the many substances that are opaque to ordinary light but are transparent to the X-rays. The black rubber or vulcanite from which ordinary combs are made, though almost absolutely opaque to ordinary light, is quite transparent to the X-rays. So, too, is the flesh, together with the blood vessels and nerves that form the soft parts of the human body. As you know, we cannot look through the body to see the bony skeleton that lies within. We can, however, see the red colour of the blood if we hold up the hand in the bright sunlight, yet the bones and other portions of the interior of the hand are invisible. Now I shall show you in this chapter how easy it is for the X-rays to pass not only through the hand, but even through the thicker parts of the body, so as to form on a suitably placed sensitive photographic plate a distinct photographic picture of the bones and some of the tissues of the body.

The exact nature of the X-rays is unknown. When they were first discovered, it was believed that they constituted a variety of light and this belief is still held by many. Since, however, the X-rays differ in so many of their properties from ordinary light, not only as regards their ability to pass through substances opaque to light, but also because they can be neither reflected nor refracted, it was necessary to explain how they differ from ordinary light. Many attempts have been made to do this.

It is claimed by some physicists that the X-rays are entirely different from light; that they consist of streams of exceedingly minute fragments 'of matter, shot out with great rapidity from that portion of the X-ray tube where the X-rays are produced. In the opinion of others, and probably of the majority of physicists, the X-rays are believed to be produced by vibrations of the ether. Some claim that the vibrations, instead of taking place as in ordinary light across the length of the ray, take place in the direction of its length; that is, that the X-rays are longitudinal ether vibrations, and not transverse vibrations.

According to still others, it is believed that the X-rays differ in no respect from ordinary light, except that their wave lengths are much smaller than the ultra-violet rays. For this reason, the X-rays have by some been called the ultra-ultra-violet rays. This matter, however, is still uncertain, and I will not attempt to describe it any farther here. Indeed, I fear I have already gone much farther than I should in a book of this scope.

When experiments were made with the X-rays, it was soon discovered that these rays were not given off from the cathode, or negative terminal of the tube, but from that portion of the tube against which the cathode rays are thrown. If an effort was made to increase the amount of X-rays produced by bringing the rays to a focus against some particular part of the wall of the tube, although a great increase was obtained in the amount of X-rays produced, yet the walls of the tube were soon melted by the increase of temperature and consequently the tube was ruined. Now, however, X-ray tubes are made so that the cathode rays strike against a heavy plate of some substance, like platinum or iridium, that is extremely refractory or difficult to fuse. In this way the proportion of X-rays produced is greatly increased.

In order readily to examine bodies by X-rays a device called a fluorescent screen may be employed. This, as represented in Fig. 85, consists of a darkened box or chamber resembling a stereoscope in shape. The smaller end of the apparatus is shaped so as to fit closely over both eyes of an observer. The larger end of the box is provided with a closely fitting plate, the inner surface of which is covered with some highly fluorescent substance, such as tungstate of calcium or barium-platino-cyanide. When the X-rays fall on this plate they pass through it and produce fluorescence on the side facing the observer, thus causing it to glow uniformly over all the parts of its surface.

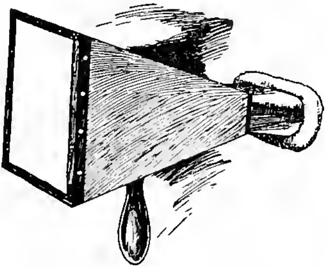


FIG. 85.—FLUORESCENT SCREEN.

Now, since after the X-rays have passed through opaque substances they are capable of exciting fluorescence in fluorescent materials, and since the light so produced is capable of causing photographic images, we come to this wonderful fact: that by the use of the X-rays it is possible to see objects that are otherwise invisible. Think of it! An object may be placed inside a wooden box with sides so thick that it is impossible to see what the box contains, and yet, if the X-rays are caused to pass through the walls of the box, and are then permitted to fall either on a fluorescent screen, or on a photographic plate, we can easily see whether the box is empty or not.

Suppose, for example, the box contains such objects as masses of iron, steel or lead, like nails, bullets, knives or needles. These objects prevent the X-rays from passing through them, so they are seen as shadows on the fluorescent screen at the places where the light or glow is absent. In other words, the objects cast shadows on the screen, so that the observer can see their positions and shape even if the box in which they are placed were made of boards six inches or a foot thick, or of 500 or 1,000 pages of a book. If, now, instead of a fluoroscope a sensitive photographic plate be placed in the path of the rays, its sensitive surface would have impressed on it all these differences of light, so that, when properly developed and fixed, it would contain an image of all it saw.

It is possible by a similar use of the X-rays to throw on a fluorescent screen, or on a photographic plate, sharply marked images of the bones of the hand, or even those of the spinal column and ribs, by causing X-rays to pass through the flesh that covers these portions of the body.

It may interest you to know the arrangement of apparatus required for thus examining the bones of the hand. If the hand be placed on a photographic plate that has been carefully wrapped in several thicknesses of blackened paper, a photograph of the bones as well as some of the tissues will be formed on the plate.

If such objects as leaden bullets, nails, pins, needles, have become lodged in any part of the human body, since, as already remarked, such objects are opaque to the X-rays, their position can be readily seen either on a fluorescent screen, or on a photographic plate, thus enabling a surgeon accurately to locate them without subjecting the patient to the pain produced by the metallic probe, which, before the discovery of the X-rays, was inserted in a wound and wriggled about until it touched the foreign body.

Photographs produced as above described, by the use of the X-rays, are known as radiographs or skiagraphs. Since, however, they are simply photographs produced by the use of the X-rays, a simpler and far better popular name is X-ray photographs.

An exceedingly curious discovery was made in the year 1896 by the French physicist, Becquerel, to whom we have before referred. This gentleman discovered that there are substances which possess the power of emitting rays closely resembling the X-rays in being able to pass through opaque substances and afterwards produce fluorescent or photographic effects. These substances, however, instead of requiring to be first placed in the light possess the exceedingly strange power of being able continually to give off this peculiar form of radiation for an apparently indefinite period of time. These rays have been named after their discoverer, the Becquerel rays.

Some time afterwards, it was discovered that, besides the salts of uranium, the name of the substance in which Becquerel had detected this curious radiation, there was another elementary substance, named thorium, that possessed a similar power of throwing off rays resembling the X-rays. Then, at a still later date, it was discovered that there exists in a mineral named pitchblend, the ore from which uranium is obtained, a number of elements that had not until that time been discovered; namely, polonium, radium, and actinium, that also possess the same properties. In some of these, as, for example, in radium, the power possessed by the rays was something in the neighbourhood of 100,000 times greater than in the rays thrown off by uranium.

The rays thus thrown off from these different substances were called respectively the polonium rays, the radium rays, and the actinium rays.

The general name of radio-active substances is given to these different kinds of matter that are thus capable of throwing off indefinitely rays resembling the X-rays. Without going any further into their peculiarities, it is sufficient to say that it is believed all polonium, radium and actinium rays, and indeed, the rays produced by all radio-active substances, consist of very minute particles of matter much smaller than the so-called chemical atoms; indeed, that they consist of small fragments of these atoms. On account of their small size and prodigious velocity they are capable of passing through matter that is ordinarily opaque to light and of producing luminous effects when they strike the fluorescent material. The light so produced causes the photographic effect.

In the opinion of some, however, it is believed that the Becquerel rays, and possibly also the rays from all radio-active substances, are due to vibrations in the ether like those that produce ordinary light, only that they are more rapid than the ultra-violet and less rapid than the X-rays. This matter, however, is as yet uncertain.

It may be a matter of surprise to you to hear that the above rays are thought to be produced by fragments of atoms. It was not so many years ago when it was believed that atoms are too hard to be cut or broken into pieces. Now, however, it is held that particles called corpuscles, whose sizes are less than .001 part of an atom, can be broken off and hurled with great velocity through space and are, therefore, capable of producing the peculiar effects of the X-rays and of the radium and other rays.

CHAPTER XXIII

ILLUMINATION. THE SALE OF LIGHT

An illumined body differs from a luminous body in that it has nothing whatever to do with the production of the light it throws off. It merely throws off in all directions light it has received from some luminous body. A luminous body not only throws off light like an illumined body, but it also produces, or manufactures, the light it throws off. When, however, the illumined body is coloured, the light it throws off differs from the light it receives. It generally receives white light, but always throws off light of the particular colours that are left after certain colours have been absorbed or quenched.

Sunlight is by far the best kind of light for the illumination of objects. In the first place it is so abundant that it is capable of producing a far more uniform illumination than any known artificial light. Moreover, sunlight is spread out over so great an expanse of sky that it lights up objects on the earth's surface far better than can any artificial light.

There are a number of luminous sources from which the light required for artificial illumination can be obtained. Some of the most important of these are the arc and incandescent electric lights, the acetylene lamp, the gas burner, and the candle.

In order that any artificial light shall act satisfactorily as an illuminant it should as nearly as possible possess the properties that characterise daylight. Let us see, therefore, what these properties are.

The object of all artificial illumination is not only to permit objects to be seen distinctly, but also, as far as possible, to give them the same appearance as when illumined by daylight. Now, one of the most important conditions for distinct vision is that the images formed on the retina shall not only be sufficiently illumined, but shall also be steadily illumined. It is necessary, therefore, that a satisfactory artificial source of light shall be steady; that is, shall continue to give off light of the same intensity.

There are few things more trying to the eyes than the attempt to examine an object closely when it is illumined by a flickering light. In such cases, the illumination of the retinal image will increase and decrease in brilliancy in a manner that is sure to produce a strain on the eyes. To attempt under these circumstances to do any work that requires close inspection, such as reading or delicate mechanical tasks, is not only painful, but is sure to result in bad workmanship. Now, sunlight is so wonderfully steady that no known artificial light can compete with it.

In the next place, in order that objects shall be distinctly seen, it is necessary that the light by which they are illumined shall possess, as nearly as possible, the same coloured rays that are present in sunlight; for, since the colour of a body is due not to the body itself but to the colours in the light by which it is illumined, it would, of course, otherwise, be impossible for the body to possess the appearance it has when illumined by sunlight.

Moreover, the artificial source of light should not markedly vitiate the air by any gaseous or other emanations. There is a great difference in this respect between the different sources that are employed for artificial illumination. Sunlight is absolutely free from obnoxious vapours, and this is a property that is by no means absent in most forms of artificial light.

A property to a certain extent resembling that above named is the heating power of the luminous source, or the extent to which it is capable of heating the surrounding air. While sunlight is accompanied by a certain amount of heat, in most cases the heating it produces is far from being objectionable, except, perhaps, during very hot weather, in close rooms. But the heating effects are by no means absent in most artificial luminous sources. Nearly all produce a far greater proportion of heat than light.

Another important property that should be possessed by a luminous source is safety. The source should be of such a character as to render it free from danger either to life or to property. Sunlight is entirely safe as an illuminant. Of course, the sunlight may be so intense that its illumination may be too great, so great, indeed, as to injure the eyes, but it is far easier to cut off a portion of the light produced by a luminous source than it is to increase it.

As regards its heating powers, sunlight may become at times so great, especially in small and poorly ventilated rooms, as to threaten life by sunstroke. With care, however, this danger is generally exceedingly small.

Sunlight is almost absolutely free from fire risks. There is no other source, except, perhaps, the incandescent electric lamp, or the day-light tube, that is as free from risks arising from the starting of fires in surrounding combustible materials.

There is yet another property of sunlight that should be mentioned; its uses in continuing the existence of plant and animal life. The presence of a certain proportion of white light resembling daylight or sunlight containing violet and ultra-violet rays is necessary.

As regards the amount of light they can produce the arc lights and incandescents come next to sunlight. These luminous sources, too, perhaps especially the arc light, come nearer sunlight as regards steadiness. When properly operated, the light they produce is fairly steady. Neither greatly heats the space it is lighting. The arc light possesses colour values that are practically the same as those of sunlight, and neither of these lights markedly vitiates the air or space around them. The open arc light does to some extent render the air slightly impure, but the enclosed arc light and the incandescent electric light are practically free from any injurious effects on the air of the space surrounding the illuminant.

One of the most serious objections to the use of the arc light as a source of illumination is the difficulty of separating a single light into a number of less brilliant lights. The difficulty exists in the case of most artificial lights, but not to so great an extent as in the arc light.

When only a single luminous source is employed for lighting a room; or, indeed, when but a limited number of sources are employed for this purpose, the objects fail to be uniformly illumined. Disagreeable shadows are apt to be produced that make it difficult for the objects to be distinctly seen. Now, incandescent lamps possess, in this respect, a great advantage over arc lamps, since the current employed for incandescent electric lamps can be readily split or divided among a great number of separate lamps. The objects illumined, therefore, are almost entirely free from shadows.

The above advantage, however, is attended by many disadvantages. In the first place, the light produced by incandescent electric lamps contains a large proportion of the reds, yellows, and orange coloured rays, with a small proportion of the greens, blues, and violet rays. Consequently, coloured objects so illumined do not possess the same appearance as when illumined by the daylight, or by the arc light. Fabrics that are blue by daylight necessarily appear dull when illumined by the incandescent light, which, as we have seen, is deficient in the blue and violet rays. The marked improvements, however, that have recently been made in incandescent lamps have to a great extent removed this objection. In that they do not vitiate the air of the room, incandescent lamps are almost as satisfactory as daylight or any other source of illumination.

Oil and gas lamps possess many disadvantages when compared with sunlight. Their fire risks are greater than either arc or incandescent lamps. They vitiate the air by pouring into it the gases formed during the burning of the oil or gas. They also render the air less fit to breathe by removing the oxygen that is so necessary for the continuance of animal life.

Another serious objection to all oil and gas lamps, is the high temperature of the gases produced in them during combustion. Moreover, these gases are produced in great volume. During hot weather the use of gas lights in the air of confined rooms, such as in weaving and spinning mills, results in so high a temperature, and the character of the work is often so poor, that it has been found necessary to shut down the mills during the night. This objection is now, however, largely a matter of the past, since practically all modern mills are illumined by incandescent electric lamps.

Another serious objection to oil and gas lamps is found in their deficient colour values. Their light possesses a preponderance of reds, yellows, and orange coloured rays, and a decreased proportion of the blues and violet rays, that is even more marked than in the case of the incandescent electric lamps. It is true that this objection has been greatly overcome by the use of acetylene gas, a variety of hydro-carbon gas that is readily obtained by the action of water on calcium carbide, a chemical substance produced in the electric furnace.

An effort has recently been made to improve common illuminating gas by the use of incandescent mantles, such as those employed in the Welsbach and similar lamps. While a marked advantage is obtained as to the amount of light yielded, such lamps producing from five to six times more light than would the same amount of gas burned with an ordinary gas burner, yet they possess the disadvantage of producing a light containing so large a proportion of greenish rays, and so small a proportion of red rays, that coloured objects, when illumined by their light, do not appear of the same colours as they do by daylight.

Perhaps one of the most satisfactory sources of artificial light is a variety of light called the Moore Electric Daylight Tube. This light is obtained by the passage of electric discharges through long vacuum tubes. The light, which closely resembles in its properties that produced by the well-known Geissler tubes, is enclosed. This luminous source cannot, therefore, render the air unfit to breathe by fumes given off, is perfectly free from fire risks, and does not heat the air of the room. Its daylight values are fairly satisfactory. The principal objection is that, as generally employed, the intensity of the light it produces is comparatively small.

You will probably be surprised when I tell you that practically all artificial sources of light with, perhaps, the exception of the Moore Electric Daylight Tube light, are very deficient in one exceedingly important respect. They are all far better sources of heat than of light. Even in the case of a good incandescent lamp there is produced only four parts of light in every one hundred parts of radiation. In other words, the ordinary incandescent lamp gives only 4% of light while the remaining 96% consists of heat. When you remember that light is what is desired from a luminous source, the heat being highly objectionable, an incandescent lamp is exceedingly unsatisfactory as an artificial illuminant, since it gives 24 times more heat than light.

The proportion of light to heat in the case of an ordinary candle is still more unsatisfactory, the candle emitting only 1½% of light and 98½% of heat. The Welsbach incandescent mantle gives 2½% of light, and 97½% of heat. And even in the case of the electric arc light there are only 13% of light and 87% of heat produced.

It seems unfortunate that all the artificial luminous sources produce so small a quantity of light in proportion to the heat. If we knew the secret of the glowworm or the firefly, we would be able to produce an artificial light far more satisfactory in its relative proportions of light and heat. And yet, even if we could do this, while we would have a very cheap light, yet it would be far from a satisfactory light source, since it would be characterised by so marked a deficiency of the reds, yellows and orange rays, and so great a preponderance of the greenish rays that would make its colour values exceedingly unsatisfactory.

In order to get the best results in the illumination of objects by artificial light, care must be taken that the light falls on the objects directly, and does not enter the eyes of an observer until after it has been thrown off from them. Under no circumstances should the light of the luminous source be permitted directly to enter the eye of the workman. When this is permitted, the image of the source will be so much brighter than the image of the illumined objects that it will be difficult, if not impossible, distinctly to see them.

Examples of poor artificial illumination are frequently seen in store windows. Take a walk some night through the business portions of your city or town, until you come to a window that is illumined by an arc light hung directly in the middle of the window. The arc lamp certainly gives an abundance of light to the articles in the window, but it doesn't throw its light on the objects so as to enable them to be seen; for, unless that side of the lamp which faces the street is covered by an opaque shield or reflector, its light directly enters the eyes of any one looking into the window to examine the goods and produces such a brilliant image of the lamp that it is difficult, and, indeed, almost impossible to see anything else, much less closely to examine the objects in the window. Nor will there be much improvement if the lamp is hung up outside the window, since, in this case, there will still be seen so bright an image of the lamp apparently in the window that the lamp is still the only thing you can distinctly see.

The proper lighting of store windows is now much better understood, so that it will be strange if you do not find somewhere in your town or city a store window that has been illumined on a different principle. In this case the luminous sources are entirely out of sight. The only light that enters the eye is from the illumined objects and under these circumstances you can see them distinctly. The luminous sources are either placed in the upper part of the window back of an opaque curtain, or they are placed back of metal shades at the sides or at the top or bottom of the window, where they are completely out of sight.

In the commercial sale of light, means must be provided for the correct measurement of the quantity of light for which a purchaser is paying. In the case of the electric light this is done by the use of the electric meter, which shows the amount of electricity that is passing through the lamps. In a similar way a gas meter is employed for measuring the quantity of gas that flows from the gas main in the street into the house. But it is not so much the quantity of the electricity or gas delivered to the purchaser that is of especial interest to him. What he wants to know is the amount of light a given quantity of electricity or gas is producing. This can be done by means of an instrument called a photometer that gives the intensity of an electric lamp or gas burner, measured in what is called candle-power, or an amount of light equal to so many candles of a definite size and composition burning so as to consume a given weight of the wax, stearine or tallow per minute.

When a luminous source consisting of a single point of light throws its light on an object, the amount of light received will be inversely as the square of its distance from the source. Suppose, for example, the light of a candle A, Fig. 86, falls on a screen B, placed say one inch from the candle. The screen will receive a certain quantity of light from the candle. If now the screen be moved twice as far from the candle, say to C, since the same quantity of light is now spread over a surface four times greater than that at B the intensity of the illumination, or the amount of light per square inch, will be only one-quarter as great as it was at B. In the same way, if the screen be moved

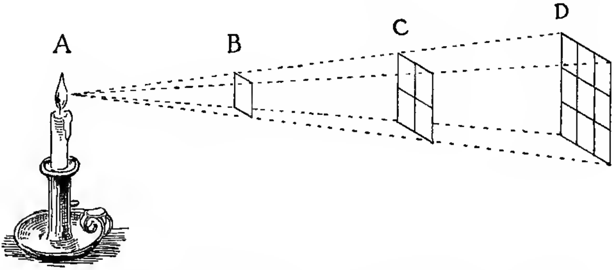


Fig. 86.—The Principle of the Inverse Squares.

to D, three times further from the candle than B, the same amount of light will now be spread over an area nine times as great, so that the intensity of the illumination at D, must necessarily be only one-ninth as great as it was at B. In other words, the intensity of the illumination will be inversely as the square of the distance; for at distances twice or three times as great as one, the intensity will be inversely as these numbers squared; for, two multiplied by two equals four, and "inversely as four" is represented by 1 divided by 4; and similarly three multiplied by three equals nine, and 1 divided by 9 or one-ninth will be "inversely as nine."

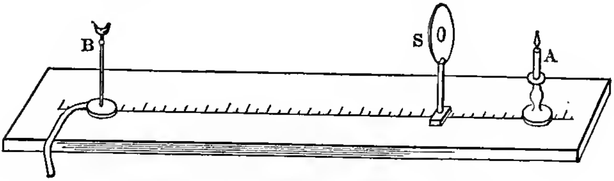


Fig. 87.—The Bunsen Photometer.

There are many ways in which the intensity of luminous sources can be measured. One of the simplest consists in a form of instrument invented by Bunsen, the German chemist. A screen of paper S, with a grease spot at its centre, is placed in the vertical position shown in Fig. 87. If one side of this disc is examined by reflected light, the grease spot will seem darker than the rest of its surface, since some of the light passes through this part of the screen. If, however, the disc is examined on the opposite side by transmitted light the grease spot will appear brighter than the surrounding parts since more light passes through it. In both these cases it is supposed that the instrument is placed in a dark room where no other light than the lights that are being examined are present.

Suppose now it is desired to know how much greater is the amount of light given off from the gas burner B, placed on one side of the screen S, than that from the candle A, placed on the opposite side of the screen. To do this it is only necessary to move the gas light towards and from the screen until the grease spot disappears when viewed from either side. Of course, both sides of the screen must necessarily be seen simultaneously. This is readily accomplished by means of suitably inclined mirrors placed on each side of the screen. When this is done the intensity of the light emitted by the two sources will be inversely as the square of their distance from the screen. If, for example, the gas burner B, is three times further from the screen than the candle A, then since the squares of three and one, are nine and one respectively, it is evident, that the intensity of the candle is one-ninth that of the gas burner, or that the intensity of the gas burner is nine times that of the candle.

It might seem, since the amount of light the eye receives from a distant object is inversely as the square of its distance from the eye, that the brightness of the image as seen in the eye should rapidly decrease as the distance increases, Now, in point of fact as you may have observed, objects at different distances from the eye appear to be of equal brightness. The explanation is obvious. As an object recedes from the eye, the size of its image formed on the retina decreases in exactly the same proportion as the intensity of its illumination decreases. If it is twice as far from the eye, although the intensity of the light it receives is only one-fourth as great as it was previously, yet since this light is concentrated on an image one-fourth the size it will, of course, appear to be as brightly illumined when twice as far off as it was in the first instance.

CHAPTER XXIV

LIGHTHOUSE ILLUMINATION AND SEARCHLIGHTS. ILLUMINATION OF THE STAGE

THE intensity of the light received by an illumined object decreases with the square of its distance from the luminous source. That is, an object illumined by an artificial source twenty yards away receives, in accordance with the law of inverse squares, a much smaller illumination than it would at a distance of ten yards. It is for this reason that the signal lights employed in lighthouses in order that distant vessels may know the general location of a coast, or of dangerous shoals, or the lights employed on locomotives that are drawing railroad trains, would soon become invisible if their rays were permitted to continue to diverge.

I remember not so very long ago, when the public buildings were erected in the city of Philadelphia, that the question arose whether it would not be easy so thoroughly to illumine the marble tower and the statue of William Penn placed on the top of the tower, at a distance of some 525 feet above the level of the street, that it could be seen distinctly not only all over the city but even at a distance of many miles from the city. The great amount of light given off by an arc light was well known, so it was commonly believed that, if a circle of twelve or more arc lights should be placed around the base of the pedestal supporting the statue, they would not only light up the white marble shaft of the column, with a dazzling white light, but would also so illumine the bronze statue that it could be seen from a great distance. This was the more confidently believed because the upper portions of the tower, including the clock dials, were covered with plates of metal that were to be covered with a coating of metallic aluminium, a metal which reflects light as well as burnished silver. But the aluminium coating proved a total failure; and, even if it had not, the fact that the illumined tower and statue, like all illumined bodies, threw off their light as diverging pencils, the decrease in intensity, as the square of the distance, would have resulted in the failure of this plan. It is not surprising, therefore, that both the marble tower and the bronze statue of Penn are absolutely invisible at a distance of a few miles only.

The rapid decrease in the intensity of the light thus emitted can perhaps be better understood from a few figures. Suppose, for example, an object is situated at a distance of one foot from a luminous source. In accordance with the law of inverse squares, the same object, if situated at a distance of 100 feet from the source, or 100 times greater, would have an intensity of illumination of $\frac{1}{100 \times 100}$ or $\frac{1}{10{,}000}$ of what it would have at a distance of one foot. If at a distance of five miles or 26,400 feet, it would have an intensity of $\frac{1}{26{,}400 \times 26{,}400}$ or $\frac{1}{696{,}960{,}000}$. It is not difficult, therefore, to realise why an object should be practically invisible at a distance of five miles if the rays of light from the luminous source be permitted to diverge.

Of course this difficulty can be easily avoided by causing the rays that come from the luminous source to be so reflected from a concave mirror, or to pass through a lens in such a way as to leave the source in directions parallel to one another. In such a case the law of inverse squares would no longer be true. The only loss in intensity of illumination would be that which would arise from the want of transparency of the air.

An extremely important case in which it is necessary to be able to see the light from a luminous source at considerable distance from it, is that of the light employed in a lighthouse. No matter how strong such a light may be, if its rays are permitted to diverge in all directions from the lighthouse, the light will so rapidly decrease in intensity that it will prove of little or no value at comparatively short distances.

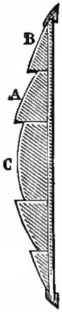


FIG. 88. LIGHTHOUSE LENS.

The means employed for causing the light in lighthouses to leave the house in the form of nearly parallel rays is to cause it to pass through various forms of lenses. Mirrors are unsuitable for this purpose, since, of course, they would shut off the light from the side opposite the metallic reflectors.

If an attempt be made to obtain parallel rays of light by the use of a single lens, this lens must necessarily be comparatively wide. It would, therefore, be apt to possess a marked spherical aberration. Moreover, it would be so thick that too great an amount of light would be lost during its passage through the glass. For this reason lighthouse lenses are constructed with a plano-convex lens surrounded by several rings or hoop-like segments with their flat faces turned towards the luminous source. This construction can be well seen from a cross-section of the lens shown in section in Fig. 88, where a single plano-convex lens C is provided with two concentric annular segments A and B, all of which have their plane surfaces on the same side as the luminous source.

The luminous sources of lighthouses consist either of powerful oil lamps, in which the supply of oil to the wicks is obtained by means of pumps, or of powerful electric arc lamps placed so that their diverging pencils of light after passing through the lens emerge parallel to one another.

In a well-constructed lighthouse lens, which produces a nearly parallel beam of light, the light, if situated at the top of a high tower, can readily be seen by vessels at distances of forty miles away.

The lighthouse lens above described was devised by Fresnel, a French physicist; so lenses of this character are generally known as Fresnel lenses. Where a broad beam of parallel rays is desired, a form of apparatus known as the Fresnel fixed light is employed. Here, as represented in Fig. 89, a series of triangular hoop-shaped prisms are placed above and below the central portion as shown. This figure shows a cross section. The actual lantern is barrel-shaped. From this lantern there would issue a broad sheet of parallel rays thrown out generally in a direction nearly parallel to the horizon.

Since there are often a great number of lighthouses situated near one another on different portions of a coast, it is necessary that some method be employed for readily distinguishing them from one another. To a certain extent this can be done by having the lights of different colours. But since very few of the different coloured rays can pass through great thicknesses of air, but little difference in this direction is possible, for red is practically the only colour besides that of the nearly white light given off from the lamp that can be used. Some other method, therefore, must be employed. This is generally done by means of what is called the flashing light.

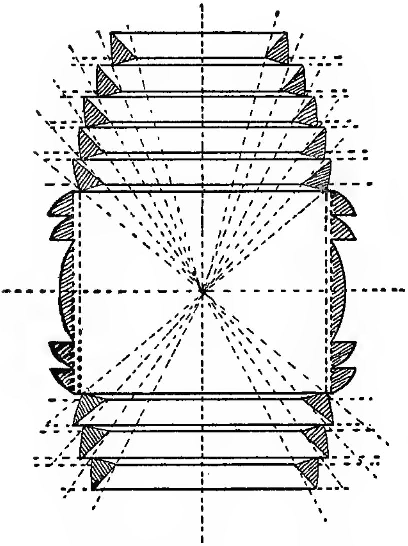


FIG. 89.—FRESNEL FIXED LIGHT.

A form of flashing light is represented, partly in elevation and partly in cross-section, in Fig. 90. Here, as will be seen, instead of having a lantern with the cylindrical outline of a barrel, its sides consist of eight separate panels formed as shown of separate Fresnel lenses, while above and below are the prismatic hoops described in connection with the fixed light. As before, the luminous source is placed at the centre of the cage or lantern. As an examination of the preceding figure will show, parallel beams of light are thrown out of the sides as indicated. If, now, by any suitable means, such as by clockwork, the cage is rotated or turned at a given rate, a distant ship will be able to see the light only when any of the

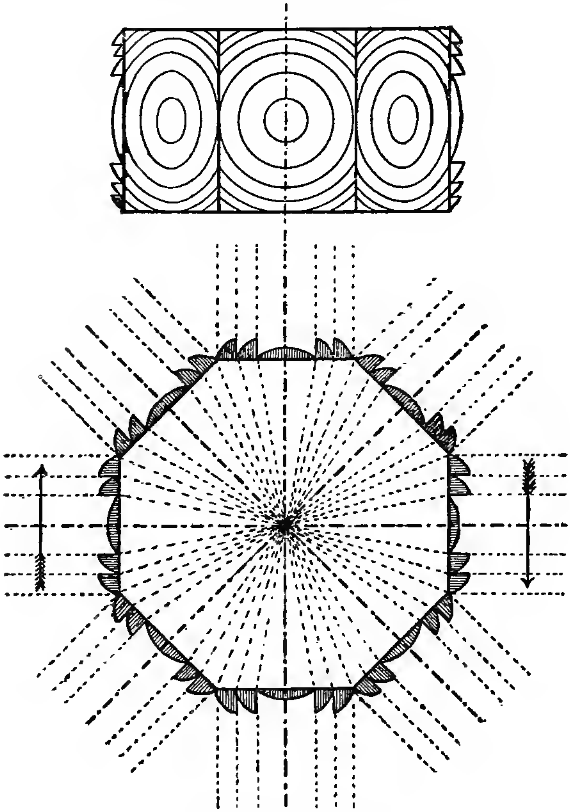


FIG. 90.—FLASHING LIGHT.

panels are turned directly towards it, the light entirely disappearing when the angular space between two neighbouring panels is turned towards the ship. Now, since, by this means, the number of times the lights appear and disappear per minute can be easily varied, it is not difficult to distinguish with certainty one light from another, especially if one or more of the panels are provided with red glasses; or, what is equally satisfactory, if one or more of the panels are entirely omitted. Both of these methods are in use.

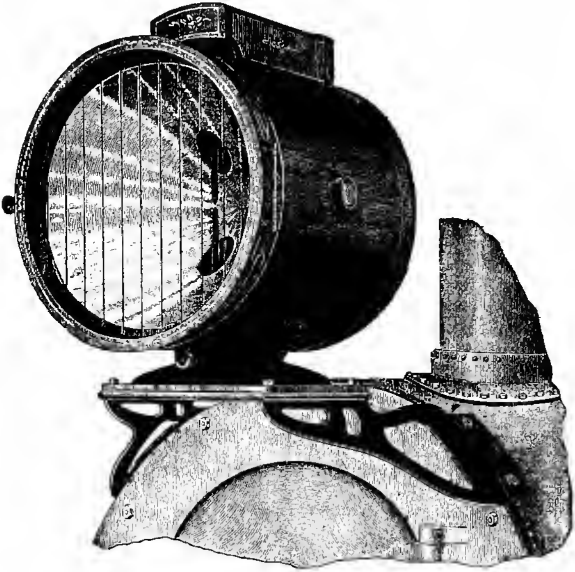


FIG. 91.—ARC HEADLIGHT FOR LOCOMOTIVE.

It is necessarily an exceedingly expensive matter properly to place such a system of lighthouses on the navigable waters of any great country so as to prevent loss to shipping. Take, for example, a country like the United States. Here it would not only be necessary to locate long lines of lighthouses at different portions of the Atlantic, the Gulf of Mexico, and the Pacific coasts, but also at different

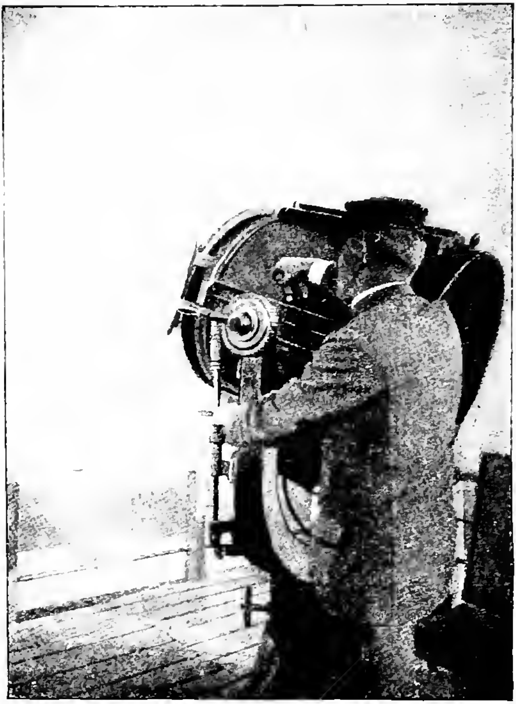


FIG. 92—THIRTY-INCH PROJECTOR ON MOUNT WASHINGTON

points on the Great Lakes and along all of its navigable rivers.

While, of course, if the rays of light coming from lighthouse lenses are absolutely parallel, they could be seen by vessels much farther off, yet under these conditions, the width of the space where such rays would fall on the ocean might be too small for use, since the light would be invisible as soon as the vessel crossed this lighted area. For this reason, a certain amount of divergence is purposely given to the rays that have passed through the lenses.

The illumination of the tracks of railroads is generally obtained by what is known as a locomotive headlight. This consists of a luminous source so placed in front of a reflector or mirror supported on the smokestack of the locomotive that it throws a slightly diverging beam of light on the track ahead. A locomotive headlight provided with an arc lamp is represented in Fig. 91.

An entirely different form of light is employed at sea, as well as on land, for the purpose of throwing a parallel beam of light in any direction, so as to discover the position of an enemy, or thoroughly to illumine some distant object. For this purpose, various forms of devices known as searchlight apparatus are employed. These generally consist of a powerful electric arc lamp so placed in front of a good reflecting mirror that the rays, after being thrown off from the mirror, shall be only slightly diverging or nearly parallel.

A form of searchlight apparatus is represented in Fig. 92. Here a nearly parallel beam of light is being thrown in the direction shown.

Speaking of searchlights, I might mention here that a much better means for lighting the statue of William Penn on the tower of the public buildings in Philadelphia, as well as making the tower itself visible at a fairly considerable distance, would be by means of searchlights that throw strong beams of nearly parallel rays on the tower and statue. This has been done with such marked success, that the light thus concentrated on the building was sufficient to enable it to be seen at a considerable distance, although the rays of light it throws off from illumined surfaces were, of course, diverging.

Fig. 93.—Stage Lamp.

Various devices are employed at the theatre or opera, for throwing either white or coloured light on objects on the stage. A common form of lamp known as a stage lamp is represented in Fig. 93. This, as can be seen, consists of an arc lamp placed at the focus of a metallic reflector, so as to throw either parallel or slightly diverging light on the object on the stage.

When it is desired to obtain on the stage effects by illumining objects, such as the dresses of ballet dancers or actresses, with different coloured lights, a lantern is employed consisting of a light placed back of a mirror and provided in front with means for rapidly changing a number of coloured glasses so as to obtain the particular colour that is desired.

CHAPTER XXV

SEEING IS NOT ALWAYS BELIEVING

I WAS always careful, when teaching natural philosophy, to impress on the minds of my students, especially those who were beginning work in the physical laboratory, that they could by no means always rely on what they *thought they saw;* that unless they had learned by extended practice, *how* to see, they might often be mistaken in what they *believed they saw.* In order to convince them of this, I advised them to take the first favourable opportunity for attending an exhibition of good legerdemain, to see how easily their eyes could mislead them.

That seeing is not always believing can be proved by a great variety of cases of what may properly be called optical illusions; that is to say, images of external objects projected on the brain through the eyes, but so modified by their surroundings that they are incorrectly interpreted.

It is only after considerable training that we are able properly to judge of the distance, size and shape of external objects. Indeed, it is often only by their surroundings that we are able to see them in their proper proportions. Under certain conditions the interpretation of images formed on the retina is so incorrect, that what we think we see is quite different from what we actually see; so optical illusions result. There are a great variety of such illusions. Of these I will describe a few, selecting those I think cannot fail to interest you.

One of the most curious optical illusions results from the fact that, under certain circumstances, we are unable to form correct ideas of relative lengths. I think that most of you, if asked to look at Fig. 94, and say which of the two lines seems to be the longer, would unhesitatingly declare that the vertical line is much longer than the horizontal line. Now, if you take the trouble to measure them carefully you will find that they are of exactly the same length. This difference in apparent length may, perhaps, be increased by making one of the two lines thicker or heavier than the other. The exact cause of this and many similar illusions is unknown.

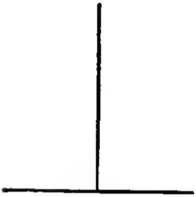


Fig. 94.—An Optical Illusion.

Of course you will ask the explanation for this illusion. Now I might, in reply, enter into a lengthy explanation, such as is given in many books that treat of the subject of optical illusions. I must confes that such explanations are so laboured that it is difficult to understand what they mean, if, indeed, they have any meaning whatever, which, in some cases, I greatly doubt. Such explanations remind me somewhat of the answer Shakespeare makes Hamlet give to the following question:

"What are you reading, my lord?"

"Words, words, words."

So I think that until you are old enough to be able to read these explanations for yourself we had better let the matter pass with the statement that the exact causes of such illusions are not thoroughly understood. My object now is to prove to you that seeing is not always believing. There is no reason for our carrying this matter further.

This inability properly to determine the relative lengths of two lines is not limited to lines drawn at right angles to each other. For example, look at Fig. 95, where the lower of two horizontal lines has exactly twice the length of the upper line. I think that most of you would say that the lower line appears less than twice the length of the upper.

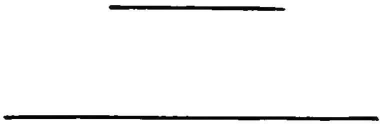


FIG. 95.—ANOTHER OPTICAL ILLUSION.

The apparent difference in length may be made more deceptive if two lines of exactly the same length have inclined lines drawn at their extremities. If, moreover, the inclined lines are doubled, the illusion as to difference in length is still more marked.

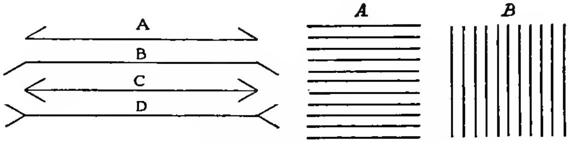


FIG. 96.—OTHER OPTICAL ILLUSIONS.

Have you ever tried to catch your friends by asking them to look at a silk hat worn by a tall man, and then have them mark off on the wall of a room a point to which they thought the top of the hat would come if it were placed on the floor? In nearly every case where the persons have not made such measurements before, the mark will be placed much higher than the point to which the hat actually comes.

In Fig. 96, the two squares formed by drawing a number of equi-distant parallel lines that are horizontal at C, and vertical at D, are of exactly the same size, and yet you cannot help acknowledging that the square at A seems to be higher than it is broad, while that at B appears to be broader than it is high; still both are true squares, as you can convince yourself by actual measurement.

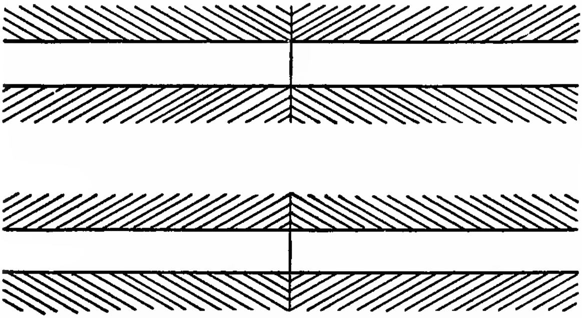


FIG. 97.—A STRANGE OPTICAL ILLUSION.

Sometimes in mechanical drawings, where shadings have been placed on the outside of parallel lines for the purpose of representing cross sections, the appearance of the drawings has been greatly injured by this peculiar optical illusion. If, again, as in Fig. 97, the oblique lines alternate, the straight lines appear to be inclined differently to each other alternately towards and from one another from the bottom to the top. You should notice, however, that in order to produce this illusion, the oblique lines should not extend across the separate parallel lines.

It is well known to printers that in some capital letters and figures, such, for example, as in the capital letters and the numerals that follow, the upper and lower lobes of the two are not exactly equal:

S S S S S S S S S S S S

8 8 8 8 8 8 8 8 8 8 8 8 8

Now, if these were actually made equal the letter S, or the numeral 8, would lose its apparent symmetry. The top of the letter is therefore made larger than the bottom as you can easily see by turning the page upside down, or by looking at the following lines in which the same characters are inverted.

S S S S S S S S S S S S

8 8 8 8 8 8 8 8 8 8 8 8 8

A number of small black circles placed closely together as in Fig. 98, will appear, when viewed by the eye, not to be circles but six-sided figures, or hexagons. This effect is produced on the retina by the black and white portions of the images. It will interest you to know how this optical illusion was discovered. It appears that a French physicist who was examining under the microscope minute forms of vegetable life known as the algæ was desirous of producing a drawing that should correctly represent on paper the appearance they thus presented. I will, however, let him tell you the story as to how he succeeded in obtaining this result:

"For a long time I occupied myself with the examination of the hexagonal appearance of the points constituting the streaks. Why should these hexagons show themselves, and how could they be other than the visible bases of small pyramids piled very closely one on the other; and if this were the case, why were not the points of the little pyramids visible? Or, was the structure before me analogous to that of the eyes of insects? Then the carapace would be but a surface of perforated polygonal openings. This latter hypothesis was attractive enough, and would have explained many things, but some careful observations with very powerful object-glasses, quite free from blemishes, had shown me that these hexagons had round points, contrary to the descriptions of micrographs. These observations, corroborated by the micrographic photographs of Lackerbauer, the much regretted designer, and by Colonel Woodward, of Washington, left not the slightest doubt that it was necessary to discover why the eye persistently saw hexagons where there were circles. To elucidate this point, it was necessary to find some means of reproducing

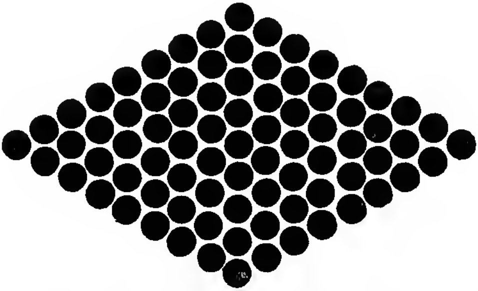


FIG. 98.—OPTICAL ILLUSION CAUSING CIRCLES TO APPEAR AS SIX-SIDED FIGURES.

artificially what nature had accomplished with so much precision on the surfaces of algæ. After many fruitless attempts, I decided on making a trial of a stereotype plate covered with dots arranged in quincunxes (i. e., in square groups of five) very close together. The result was more successful than I had hoped; the effect produced is exactly that of the arrangement of the so-called hexagons of the most beautiful of the algæ, the *Pleurosigma angulata.* If these stereotypes are examined with one eye only, we shall be immediately convinced that we have to do with hexagonal polygons."

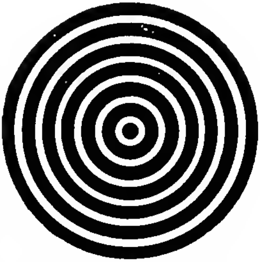


Fig. 99.—Sylvanus P. Thompson's Optical Illusion.

Professor Sylvanus P. Thompson, the English electrician and physicist, gives the following curious instances of optical illusions: In Fig. 99 a series of concentric black circles, alternating with white circles, are drawn as shown. If now a card on which these circles are drawn be given a circular motion, the circles will seem to rotate, this rotation being in the same direction as the rotation of the card. If, however a cogged wheel in white is drawn with the black enclosing line as represented

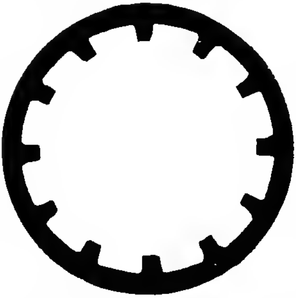


Fig. 100. Optical Illusion. Apparent Rotation of Cog Wheel.

in Fig. 100, then, on the rotation of the sheet, the cogged wheel will appear to rotate, but this time in the opposite direction to that of the rotation.

The illusion is more satisfactory if a number of concentric circles are drawn around the cogged wheel.

There are many other curious optical illusions, but I think the preceding will suffice to prove the statement made that seeing is not always believing.

CHAPTER XXVI

EFFECTS CAUSED BY PERSISTENCE OF VISION

There are a number of curious effects caused by the persistence of the retinal image; i. e., by the fact that the images of objects, viewed by the eye, do not immediately disappear when the light producing them is cut off. So many different effects are produced in this manner that I can only call your attention to some of the more striking.

It is easy to see both sides of a silver half dollar at the same time. To do this it is only necessary to spin the coin on its edge by giving it a sudden twisting motion. As the opposite sides are turned alternately towards and from the eyes the retinal images continue, so that both sides can be distinctly seen at the same time.

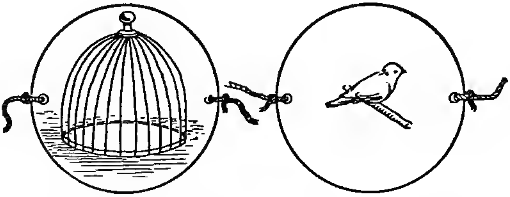


Fig. 101.—The Thaumatrope or Wonder Turner.

An optical toy known as the thaumatrope—or, as the word means, "the wonder turner"—is based on the same principle. This toy, which, by the way, has been known for many years, consists, as represented in Fig, 101, of a stiff card, on the opposite faces of which two different pictures have been drawn. When the card is rapidly twirled, by twisting the ends of strings attached to two of its opposite edges, the pictures placed on the opposite faces appear as a single picture. You can show your ingenuity by devising a number of laughable effects by drawing different pictures on the opposite faces of a card; for example, a pair of spectacles on one side, and on the other a man's face. If on one side of the card you make a drawing of a cigar or pipe, you can readily add these objects to any photograph of a man or woman that is placed on the opposite face.

A similar form of optical apparatus is known as the zootrope. In this apparatus successive pictures of men or animals are placed at suitable intervals on a long strip of paper, so as to leave between them blank spaces of a certain length. The figures represent animals or men at different times during a certain movement, such as jumping over a fence, or running after and catching something. The paper strip with its figures is placed inside a cylindrical box, so as to be viewed by a person on the outside through a number of vertical slots. A rapid rotation is given to the cylinder and, since the figures inside can only be seen while the slots are passing the eyes of the observer, the pictures are only seen momentarily. They do not, however, entirely disappear, owing to the fact that their images persist or remain on the retina. If the pictures have been properly drawn, so as to represent correctly the successive movements of the animals, or the person, they will appear as a single continuous picture in which the moving objects appear correctly to go through their proper motions.

Of course you will understand that, in any device in which motions are produced by viewing successively a number of pictures, it is necessary that these pictures correctly represent the positions occupied by the animals or persons at different parts of their motions. The best method of obtaining such pictures is to take successive photographs at different times.

Edison has devised the familiar moving picture apparatus known as the biograph and by a number of other names. The successive pictures for this apparatus are taken on a long photographic film that is wrapped around the surface of a cylinder, from which it is rapidly unwrapped by any suitable mechanical means. Each picture is brought successively before the image-forming lens of a projecting lantern, and, being powerfully illumined by an electric light, casts a succession of images on a distant screen. These images, being successively seen by the audience do not appear as separate pictures but as if they consisted of a single picture, representing people, animals, etc., as going through lifelike movements. In this way representations of people running, dancing, jumping, walking, etc., are given in a very comical manner, and, since the photographs correctly represent the expression of their faces at different times, the effects produced are often exceedingly ludicrous. This is especially the case if, as is sometimes done, the figures are apparently made to talk to one another by the use of a phonograph.

I remember seeing a very remarkable picture thrown on a screen by a moving picture apparatus. It represented a locomotive approaching the audience from a distance. In order to add to the effect, the picture of the locomotive, when first seen on the screen, is not only small but is purposely poorly illumined. It gradually grows more and more distinct and somewhat larger, and appears to be coming rapidly nearer and nearer the stage. In order to increase the illusion, rumbling and rattling sounds are sometimes added, and, just as the locomotive seems ready to hurl itself off the stage onto the audience, a man is represented as crossing the track safely just before the locomotive rushes by.

A variety of moving discs or spinning tops, that depend for their effects on the persistence of vision, are employed for the mixing of different coloured lights in the eyes of an observer. One of these has already been referred to. You will remember that this apparatus consists of a circular disc capable of being rapidly rotated. The disc is divided into segments of different sizes and painted with the colours of the solar spectrum. The colour in each segment is seen as a continuous band or ring just as would be a bit of glowing coal or wood if whirled rapidly in a circle. The different coloured bands or circles being mixed together in the eyes produce the appearance of white light.

As is well known, a mixture of black and white paints produces grey. There are various ways of ensuring this mixture of the white and black. For example, a disc, painted with alternate segments of black and white, when rapidly rotated, completely loses the marked contrast it presents when at rest, but seems to be covered with a uniform coating of grey. This effect, however, will not be seen until a certain rapidity of movement has been reached.

If, on the contrary, the disc is painted as represented in Fig. 102 with a six-pointed star as shown, when a sufficient rapidity of rotation has been reached, its surface, instead of being uniformly coloured, will show a series of concentric circles, the centre of which will be pure black and the remaining circles of different shades of grey that rapidly become lighter towards the edge of the disc. A little thought will explain the cause of this. Around the centre of the disc there is a continuous dark circle so that here black only will be seen, while, as we proceed towards the circumference of the disc, the amount of white that will be mixed with the black will become greater and greater, thus producing lighter shades of grey.

FIG. 102.—MIXING BLACK AND WHITE IN THE EYE.

There are other ways in which these rings can be produced; for example, by the rapid rotation of a disc with jagged spokes. The result is a series of concentric rings of varying shades of grey produced by the admixture of the blacks and whites.

If, instead of employing whites and blacks, two different colours are used, then instead of having greys produced by the mixing of the colours on the retina, various colours will result.

It makes no difference what means are employed for the rapid rotation of the disc. A simple form of top devised for this purpose by Helmholtz consists of a heavy brass disc, the weight of which causes the top to continue spinning for a long time after it has been set in motion by the rapid pulling of a string wrapped around its vertical axis. Discs of coloured paper can be placed on the upper part of the top. By cutting a slot from the centre to the edge, as shown in Fig. 103, two differently coloured discs, say a red and a blue, can be slipped over each other through the slot so that a half, a third, or a fourth, etc., of the red disc shall cover the blue disc. Then, when the top is rotated, a colour will be produced such as would result from the mixing of two, three, or four times as much red as blue. In the same way different coloured discs can be employed. When blue and yellow discs are employed, a great variety of different greens are obtained, or when red and yellow discs are employed, different shades of orange result, etc.

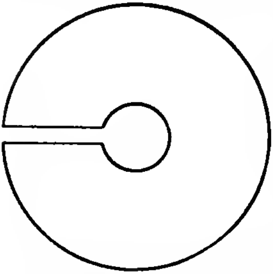


FIG. 103.—PAPER DISC FOR COLOUR TOP.

Perhaps, one of the most interesting devices in the way of tops for producing curious effects caused by the persistence of vision, is found in a device that is sometimes called a dazzling top.

The dazzling top consists of a modified form of the top devised by Helmholtz. Its axis is provided with a hollow stem, so that when the top has been set in motion in the usual manner, by pulling a string, different shaped wires or pieces of metal can be slipped into the hollow axis. These wires, or pieces of metal, being highly polished, as soon as they acquire a sufficiently rapid motion, produce, like the point of a rapidly rotated lighted stick, a series of luminous circles. In this way the gauzy outlines of vases, bowls, saucers, plates, and discs are produced in an exceedingly wonderful manner.

CHAPTER XXVII

GHOSTS

THERE are two kinds of ghosts; ghosts that have no existence whatever save in a disordered brain, or in a brain over which the mind has no control, and ghosts that are caused by actual pictures formed on the retina by invisible objects, and therefore believed to be of supernatural origin, that is, belonging to beings from another world.

We have, so to speak, two kinds of eyes, the eyes of the mind, and the eyes of the body. The eyes of the mind are able to conjure up images that at times seem quite as distinct as those seen by the eyes of the body. It is these two kinds of eyes that give rise to the two kinds of ghosts above referred to.

And first as to the ghosts that have no existence, save in a mind that is beyond the control of the will power, and, therefore, is not to be relied on as to the accuracy of its images. When we are asleep, and dream, our eyes are shut; there is no possibility of the existence of any true retinal images. Our will power is lost; our thoughts flow on automatically, sometimes in a sensible coherent order, but generally in an extremely curious way, so that the things we dream of consist of strange mixtures of the possible and the impossible.

Now this peculiarity characterises all our dreams. No matter how curious and wonderful they may be, they never surprise us. It makes no difference whether the times, places, or circumstances are contrary to what we could have expected them to be. We see and talk with people we know have long ago been dead, but they appear as we knew them during life. They talk with the same voices they had during their lifetime. It seems natural that they should be talking with us. The same is true, if these imaginary people happen to have died hundreds and thousands of years before our time. It is all one and the same thing, and seems perfectly natural. We may dream we are talking with Christopher Columbus, the discoverer of America, with George Washington, the saviour of his country, with the great Lincoln, or with any other of the people who have long ago been dead and buried, and nevertheless this fact fails to surprise us.

No one can tell just how different ideas get into our brains during dreams. It seems, however, that our dreams are based on actual impressions received during our waking hours. Dr. William B. Carpenter, in his Principles of Mental Physiology speaks as follows concerning this point:

"There can be no doubt that the materials of our dreams are often furnished by the traces left upon the brain by an occurrence that has long since passed and which has completely faded out of the conscious memory."

As an illustration of this fact Carpenter says:

"The following circumstance recently mentioned to the writer by an eminent judge, one of whose mental experiences has already been cited, affords a characteristic illustration of this kind of cerebral action. Having been retained, before his elevation to the bench, in a case which was to be tried in the north of England, he slept at the house of one of the parties in it; and dreamed through the night that lizards were crawling over him. He could not imagine what had suggested such an idea to his mind, until, on going into the apartment in which he had passed the evening he noticed a mantel-piece clock on the base of which were figures of crawling lizards. This he must have *seen* without *noticing* it; and the sight must have left a "trace" in his brain, though it left no record in his conscious memory."

Ideas of time appear to be strangely lost sight of in our dreams. Instances are on record in which people have dreamed of occurrences that have continued for long periods of time, when it was certain the person had been asleep only a few minutes, and, possibly, only a few seconds. Indeed, it is believed by some, who have given this matter careful thought, that dreams covering a long succession of events have been started by a sound that awakened the sleeper; that it is only during the short interval between a previous condition of deep sleep and being fully awake, that all the dream impressions have been produced on the mind, or in other words, that all our dreams occur during that short time which exists between sleeping and waking.

It is not an uncommon experience that when there seems to be an imminent danger of death, as, for example, by drowning, that the entire previous life of the person appears to pass almost instantaneously before his mind like a rapidly changing panorama.

There are, however, what may be called day dreams that occur when our eyes are wide open, and when we believe we see some object to which, however, we attach entirely inconsistent ideas. If, now, we can, in our dreams distinctly see pictures either of the living or dead, it is not surprising that we should also see in day dreams, appearances of people who might, perhaps, properly be called ghosts. Nor is it only to weak, disordered brains that such day dreams come. I am sure no one would accuse Sir Walter Scott, the great writer, of possessing a weak intellect, and yet day dreams were common to him. In Scott's book on "Demonology and Witchcraft," he gives an interesting account of one of these day dreams:

While attentively reading, shortly after the death of his friend, Lord Byron, an account of his habits and opinions, Scott tells the following of a friend:

"Passing from his sitting-room into the entrance-hall, fitted up with the skins of wild beasts, armour, &c., Scott saw right before him, and in a standing posture, the exact representation of his departed friend, whose recollection had been so strongly brought to his imagination. He stopped for a single moment, so as to notice the wonderful accuracy with which fancy had impressed upon the bodily eye the peculiarities of dress and posture of the illustrious poet. Sensible, however, of the delusion, he felt no sentiment save that of wonder at the extraordinary accuracy of the resemblance, and stepped onwards towards the figure, which resolved itself, as he approached, into various materials of which it was composed. These were merely a screen occupied by great-coats, shawls, plaids, and such other articles as are usually found in a country entrance-hall. Sir Walter returned to the spot from which he had seen this product of what may be called imagination proper, and tried with all his might to recall it by the force of his will, *but in vain*—a good illustration of the slight influence of volition over sensation, compared with that of a vivid mental image or idea acting upon the sensorial centres and distorting or moulding into other forms the impressions received from objects of sense."

When one has formed a vivid mental picture of a certain thought he may, while looking at some object, see not the object itself but the mental picture so distinctly that it seems to possess as much reality as if it actually existed. Thus Dr. Carpenter tells the following story that illustrates this matter:

"During the conflagration at the Crystal Palace in the Winter of 1866-67, when the animals were destroyed by the fire, it was supposed that the chimpanzee had succeeded in escaping from his cage. Attracted to the roof, with this expectation in full force, men saw the unhappy animal holding on to it, and writhing in agony to get astride of one of the iron ribs. It need not be said that its struggles were watched by those below with breathless suspense, and, as the newspapers informed us, 'with sickening dread.' But there was no animal whatever there; and all this feeling was thrown away upon a tattered piece of blind, so torn as to resemble, to the eye of fancy, the body, arms, and legs of an ape!"

Here, a tattered piece of window blind only was seen, and yet it seemed to consist of the body of a chimpanzee, that was dying in great agony in the flames.

Carpenter also tells the following somewhat similar story:

"A whole ship's company was thrown into the utmost consternation by the apparition of the cook who had died a few days before. He was distinctly seen walking ahead of the ship, with a peculiar gait by which he was distinguished when alive, through having one of his legs shorter than the other. On steering the ship towards the object, it was found to be a piece of floating wreck."

It is not surprising, therefore, that there are apparently well authenticated stories of ghosts who have been seen under different circumstances by people, and, moreover, by people of unquestioned mental ability, people of strong mentality concerning whose integrity and reliability there can be no question. But we can no more believe in the reality of these illusions than we can in the bodily existence of the people we see in our dreams. These appearances consist of those unsubstantial things of which dreams are made. They are mere creations of the imagination.

We come now to ghosts of the second kind; i. e., appearances of objects whose images actually exist on the retina. These objects being invisible, their images are assumed to be of supernatural origin, or to constitute beings from another world.

To a certain extent, our estimate of distance depends not only on the size of the object, but also on the amount of its illumination. Suppose now, while in a room that is too dark to prevent any one from seeing the position of a distant screen, that, by means of a magic lantern, the picture of a small object suddenly appears on the screen; for example, a skeleton. The illumination given to this image being small, and the image itself being of small size, it seems to those in the room to be situated at an enormous distance. If now by a slight movement of the lantern, the size of the image is caused to increase rapidly and the amount of its illumination is also increased there will be presented to the audience the optical illusion of a skeleton rushing with terrible speed towards them.

The magic lantern employed for the above purpose is called a phantasmagoria. It differs from an ordinary lantern only in its optical details, and in being mounted on rollers so that it can be moved towards or from the stage. This form of lantern was produced by an English optician named Robertson, and was first brought out in the city of Paris. By its use Robertson succeeded in giving a number of exhibitions in the city of Paris which created an unusual excitement even in that readily excitable city.

It appears that Robertson from a very early age was greatly interested in the so-called black art. He thus referred to this fact:

“Who has not in his younger days believed in witches, hobgoblins, and compacts with the devil? I know I did, and worse; for I imagined and fully believed that an innocent old woman who was a neighbour of ours really had dealings with Lucifer, as every one asserted. I even went so far as to envy her the power of conferring with the Evil One, and once shut myself up in my room with an unhappy live cock, whose head I cut off in the most barbarous manner, having heard that that was the most approved manner of summoning into one’s presence the great head of all the demons. I waited for him for several hours, calling on him to appear, threatening to deny his existence for the future if he did not appear, but all to no purpose. The books on magic and the black art that I had read had completely turned my head. I believed everything that was in them, and I desired ardently to perform the wonders they described, even with the aid of the devil. '*The Magia Naturalis of Porta*' and the '*Recreations of Midorge*,' which treated simply of natural phenomena, had no effect upon me, but I was at last obliged to fall back on the principles involved in them, in order to create the diabolical appearances I had sought after in what I considered a truly supernatural manner, until at last my dwelling became a true pandemonium.

"It is only our grandmothers, it has been said for a long time, who believe in magic, witches, and supernatural appearances; but the statement is hardly true, seeing how easily the country people fall a prey to the first cheat who chooses to invest himself with supernatural powers. We have sufficiently ridiculed the superstitions of the ancients, and numberless instances may be adduced which are a shame to their intelligence, and which give, so to speak, a denial to the stories we have heard of their high state of civilisation. But, I believe, if we were to make a collection of all the stories of ghosts, of mysterious appearances, of communications between the living and the departed, of the discoveries of hidden treasures, &c., &c., which have taken place, even since the Revolution, before whose power so many dark things have been brought to light, the collection would hardly be less bulky than that of the ancient superstitions now happily passed away."

Perhaps one of the most wonderful public productions of ghosts before large audiences was that of M. Robin, a French prestidigitateur, one of the most celebrated successors of the great Robert Houdin. Robin produced the ghost I am about to describe in Paris during the year 1847. Since that time it has been modified and greatly improved.

Of course you wish to know how such a ghost can be raised on strictly scientific principles. If you examine Fig. 104 I think you will have no difficulty in understanding how this is accomplished. The figure shows a vertical cross-section of a theatre with the audience on the left, and the stage on the right-hand side. Beneath the stage is a person dressed as a ghost. A powerful light is thrown on him from a lantern, and the diverging pencils of light from his illumined body, being reflected from the surface of an inclined sheet of clear glass, are seen by the audience as an image on the other side of the glass immediately in front of an actor placed as shown.

In order to keep up this illusion, it is necessary that this actor shall never come into such a position on the stage as to appear directly before the plate of glass. If he did, the glass plate, hitherto invisible to the audience, would at once be seen, thus of course destroying the illusion.

In this exhibition every care is taken to raise the expectation of the audience. The lights are lowered in the theatre, and to the accompaniment of faint music by the orchestra, the villain, in this case the actor, becomes reminiscent and tells of the many murders he has committed. At last the ghost comes, as it were from the grave, to wreak vengeance on the man who had brought his existence on the earth to a premature end. The murderer rises, sends an

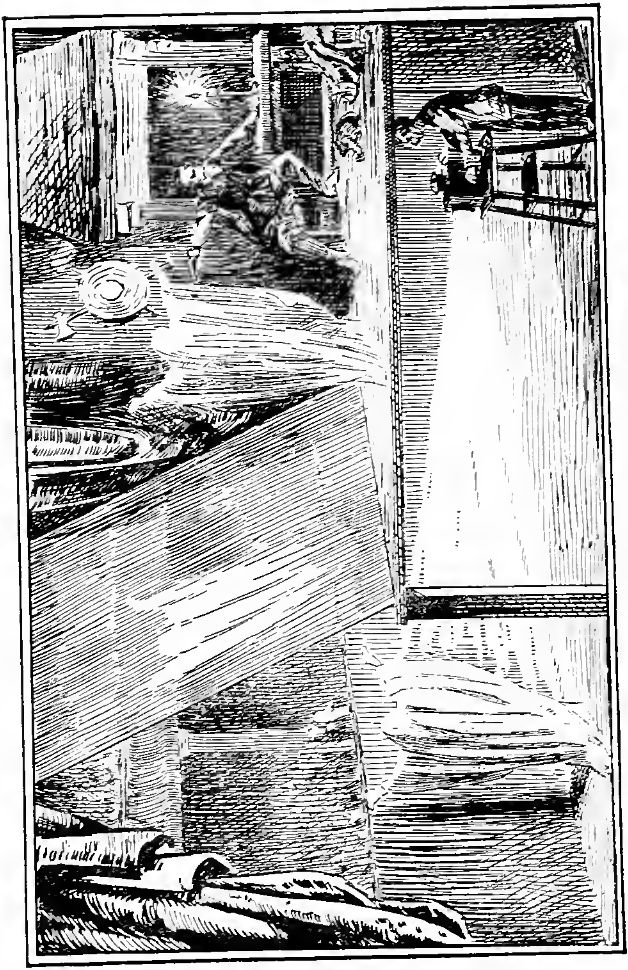


FIG. 104.—A SCIENTIFICALLY RAISED GHOST.

imaginary bullet through the ghost, and even pierces its heart with a rapier. But, to the intense delight of the audience, who has paid to be fooled, and insists on having full value for its money, the ghost, aided by a hollow laugh from a person in the wings, shows its scorn for pistol balls or rapier stabs, and the audience goes home to tell in language, that is more enthusiastic than accurate, of

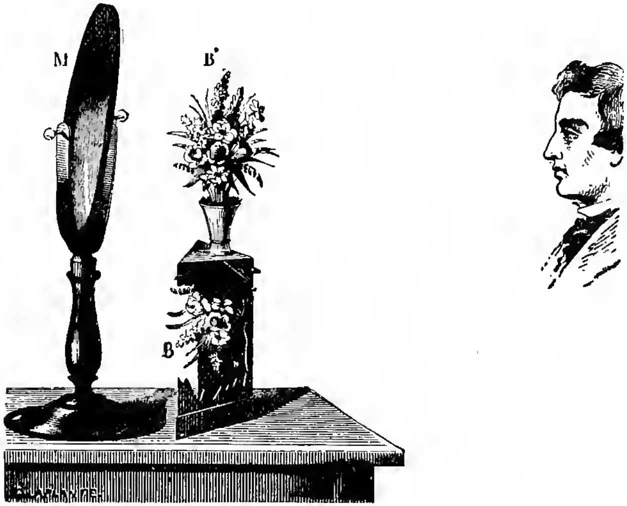


Fig. 105.—The Phantom Bouquet.

the wonderful things it has seen, though, of course, you or I could tell them that seeing is not always believing.

I might add to this chapter a number of other illusions produced either by reflection from mirrors, or refraction from lenses. For example, in a well known illusion called the "Phantom Bouquet," a bouquet is seen by the aid of a concave mirror M placed as represented in Fig. 105, under circumstances where the object producing it is invisible. The bouquet B, is supported in an inverted position on the open side of a box placed as shown. By giving the mirror an inclination the image of the bouquet will appear to the observer in an upright position B′ resting on the top of the box, just as if it were a real bouquet, when, of course, a stick can readily be passed through the image without injuring it.

Sometimes images produced by lenses or mirrors are formed on clouds of smoke or incense acting as a screen. This is probably the reason ancient necromancers, who appear to have had some knowledge of optics, always burned incense when they desired to raise people from the dead, or called on genii to appear.

Fig. 106.—An Easily Raised Devil.

All the cases I have given of ghosts, especially the ghost of Robin, required complicated apparatus. Now I will show you how easily you can command a spectre to appear on the ceiling of a room by no more complicated mechanism than the figure of a devil or any other grotesque shape, cut from a piece of white paper, with a little hole at the centre, as shown in Fig. 106, and placed on a black cloth or sheet of black paper, where it will receive a flood of light. After keeping your eyes fixed on the hole at the centre of the paper, for at least half a minute or longer, suddenly direct them to the ceiling of the room, preferably to a portion of the ceiling that is not brightly illumined. You will then see, as plain as plain can be, a demon face grinning at you from above, only now all the dark parts appear illumined, and the white parts appear dark. If you wish to vary this appearance, it is only necessary to use coloured instead of white paper; for if you cut the devil out of green paper he will appear on the ceiling in his everyday suit of fiery red.

CHAPTER XXVIII

SUNSHINE AND GLADNESS, MOONSHINE AND MADNESS

I AM sure you will have no hesitation in believing that sunlight produces gladness, but I hope you will not believe that moonlight tends in any degree to produce madness; for I feel sure this is not true. Indeed, there is no reason why it should be true, because, after all, moonlight is only sunlight thrown to the earth from the surface of the illumined moon.

The merry, merry sunshine has long been recognised as ensuring that buoyancy of feeling, or exuberance of bodily health and mental vigor, that is sure to result in happiness and gladness. One feels happy in the sunlight and gloomy and sad in the darkness. Animals, like plants, do not flourish in the dark and, if deprived for too long a time of the stimulating power of light, will gradually droop and die.

It is but fair, however, to say that there can be so great a stimulation produced by prolonged exposure to sunlight that it may eventually lead to decreased vitality. In the temperate zone, where there is practically never a marked excess of light, we can safely expose ourselves to the light and heat of the sun for long periods of time, although even here we may overdo the matter and receive so great an amount of light as to be seriously injured. But in the tropics, where there is so great an abundance of sunlight, it is necessary that people like you and me, whose skins are white, beware of exposing ourselves too freely to the full rays of the sun, since, otherwise, we may be greatly injured. While this injury is produced by general exposure of the body to sunshine, it is especially the eyes that should be guarded under these circumstances. It often happens that people from the temperate zones, on going to live in the tropics, unless they take the precaution to protect their eyes by coloured glasses, find their eyesight seriously affected by the great flood of light.

On the higher mountain ranges, where the slopes are covered with snow, unless the eyes are protected from the intense light thrown off from the snowfields, a form of blindness frequently occurs. It will interest you to know that there is a disease of the eyes similar to snow-blindness that sometimes occurs in the tropics, and is due to the excessive light of these parts of the world.

While an excess of light is apt to be attended by bad results; yet, when taken in moderation, light unquestionably acts as a stimulant to our bodies as well as to the bodies of animals. As is well known, exposure to light increases the ability of the blood to carry with it the life-giving oxygen that is taken from the atmosphere during breathing. Moreover, in a similar manner, an exposure to the light aids the blood in giving off, or getting rid of, the carbonic acid gas that is produced in different parts of the body, by the oxygen burning the impurities out of the blood.

Under certain conditions, what may be called light hunger exists in animals. This hunger is apt to occur in the case of dark skinned races like the negroes. When negroes are brought from a tropical climate to this country, they will often manifest light hunger in an unmistakable manner. You have probably noticed how in some portions of the temperate zones of the United States, negroes appear to take delight in lying, or even sleeping, in the full sunlight. If you or I should do this, we would soon get too much of a good thing. The negro is able to do it for two reasons; first, because his body has become accustomed to it during many generations; and, second, because his skin is dark coloured, and, therefore more opaque to light than our white skin. You know that the life in the open air and the exposure to the full sunshine you have when you go to the country, and especially to the seashore, produce a bronzing, tanning or browning of the skin. Now beyond doubt this darkening of the skin is an effort on the part of nature to protect the body from too free exposure to the sun.

Exposure to sunlight produces stimulation just as a drink of wine or alcohol produces stimulation. But it does not follow that because a moderate exposure to the merry sunshine stimulates the body and mind, thus making you feel glad and happy, that an over-exposure is desirable.

Exposure to sunlight causes gladness by a stimulation of the mental powers. Some of our best known literary men actually basked in the sunlight. Charles Lamb greatly enjoyed the bright sunny skies of Italy. Goethe talks about sun-thirst. Southey was fond of writing while lying in the hot sunshine on the white beach at the seashore.

The lower animals appear to recognise this stimulating power of light. Dr. Woodruff tells about a certain species of ants that are in the habit of bringing the eggs out of their dark underground nests for a short exposure to the bright sunlight. As is well known, if left too long in this light the eggs would be killed. A short exposure, however, appears greatly to aid in their germination and subsequent growth.

Perhaps one of the best instances of the good effects of sunlight is found in a statement recently made in the *New York Medical Journal* (January 24th, 1903) that houses in New York City, situated on the north side of the streets that run east and west, show a higher death rate in such diseases as pneumonia, consumption and kidney troubles, than houses on the south side. He concludes that the reason for this is that the people living on the south side of the street get more light and air since, during the winter, they spend so much of their time in the rear rooms, which are sunnier, lighter and warmer.

It is because of the well-known effects produced on the human body by sunlight that various kinds of treatment have arisen for the curing of disease by exposure either to the white light of the sun, or to certain of its coloured rays. Such methods for the treatment of diseases are known by the scientific name of actino-therapy, or, what you may call, light-cure.

The lower or infra-red rays of the spectrum, as well as the ultra-violet rays, have been especially employed in the cure of diseased conditions of the body. In this treatment light, passed through coloured glasses, is permitted to fall directly on the body of the patient, or is concentrated on particular parts by means of lenses.

The violet or the ultra-violet rays are, perhaps, employed most frequently in light-cures. While, in certain cases, unquestioned good has resulted from the exposure of the body to concentrated violet light, yet it appears that serious effects may follow a too prolonged exposure.

I was once told by a well-known English Army officer that, during the prevalence of cholera in India, some thirty odd years ago, it was his experience that the best method of sterilising water, or rendering it fit to drink by killing any cholera germs it might contain, was to permit the water to run in a thin stream where it was exposed to direct sunshine.

There are various methods employed for the treatment of diseased bodies by their exposure to the light. Sometimes the patients are merely bathed in light of different colours by placing them in a room in which all the light that enters has passed through variously coloured glasses in the windows. Sometimes, however, powerful pencils of light are concentrated on different parts of the body by means of lenses. Now while many diseases are greatly improved by such an exposure to violet light (for this unquestionably results in the death of the germs causing those diseases) yet, unless care has been taken, there may be so great a stimulation of the surrounding tissues that there is a danger of gradually destroying them. Therefore, while the patient may be cured of some particular disease, yet he may die of another and even worse disease produced by the death of the surrounding tissues.

Various forms of what are called light baths are employed. These for the greater part consist of small cabinets containing a great number of incandescent electric lamps and in some cases arc lamps. Such a quantity of light in a small space, especially in the case of incandescent electric lamps, may cause the temperature of the air in the bath to rapidly rise, soon reaching as high as 122° F., or even 140° F., so that the patient soon begins to perspire freely.

When intelligently administered, and not used in excess, light has been known to produce beneficial results.

It is believed by some that exposure of the body to different coloured rays of light produce effects that vary with the colour. For example, it is said by some that exposure to the red rays produces a stimulation or excitement of the nervous system. This is probably the reason red excites a bull. It is also claimed, on the contrary, that exposure to the ultra-violet rays produces a depression of the nervous system.

But I think I have now said enough to prove that sunlight tends to gladness. And now as to the dismal statement that moonlight tends to madness. I am glad to say that as far as I have been able to discover from my reading, no evidence whatever has been adduced to show the correctness of this statement. It was, however, at one time generally believed. Indeed, the word lunatic, in its derivation from the Latin word *luna,* the moon, is based on the belief that lunatics owed their madness to exposure to moonlight.

A belief in the ability of the moon to work spells or produce ill effects on people has existed from the earliest times. These beliefs are so ridiculous that I only mention them here to show you how far people will let themselves be fooled. For example, in some parts of the world it is firmly believed that, if an unbaptised child is exposed to the rays of the moon, it will be unfortunate all the rest of its life. If you have ever had a run-around on your finger, or a felon or swelling under the nail, you will not need to be told that they are painful; for you will know that by experience. It may interest you, however, to know that there are countries where it is claimed that you brought these swellings on yourself by pointing this finger at the moon. Another equally foolish belief is that if the hair of the head is cut while the moon is increasing, or apparently growing bigger every day, headache will result.

The astrologers firmly believed that the moon governed the brain and thus caused madness. Every now and then the newspapers, possibly with a desire to "poke fun" at people who are weak enough to believe that the moon's light can affect the brain, publish a new moon hoax. This willingness to ridicule believers in the moon seems to have existed as long ago as the time of the Grecian author, Lucian. Lucian, who was a great wag, asserted that one night, while asleep on the earth, he was wafted to the moon where he met Endymion, the shepherd. You may possibly know that the great ambition of Endymion was that he should always remain young, and should be permitted to sleep as long as he wished. Lucian declares that when he reached the moon he found Endymion asleep, and since he was himself wafted there while asleep, the account he gives of the moon may be regarded as moonshine, the stuff that dreams are made of. In describing the people on the moon, Lucian says they lived on frogs that they cooked over a fire, but that, instead of eating the flesh, they simply breathed in the smell that came from the cooking. Another peculiarity of these people was the odd habit they had of taking their eyes out of their heads so as to keep them from seeing any thing that displeased them. Now this was certainly an exceedingly foolish habit; for, when they mislaid their eyes, they were obliged to borrow those of their friends. But enough of this nonsense, which I only mention to show you that it is possible for one to be madder than a March hare by having one's head filled with this kind of moonshine.

CHAPTER XXIX

PHOTOGRAPHY

When you get to thinking about it there are very few things that are really more wonderful than the taking of a photograph. I have sometimes heard people praised because they are able to see so much at a single glance. Such people, looking but for a few moments at a collection of objects in a large store window, are able to remember, and record in writing, a greater number of the objects than you would believe possible. These people are properly praised both for their powers of observation and for their great memories. But the best of them cannot begin to compare with a photographic plate, either in its quickness of observation, or in its wonderful memory. When suitably placed in a camera, focused on a crowded audience, and permitted to remain exposed but for a small fraction of a second, a photographic plate is able both to record and to remember the smallest details of all objects in view. Not a single person in the audience who is placed so as to be in the view of the camera is missed. And not only this, but even all the peculiarities of size, height, clothing and sex are clearly marked. In the same way, if the camera is pointed at a landscape, there is not a single blade of grass, a flower, a tree, or even a leaf on the trees, in sight, that the photographic plate does not recognise and record. It is, indeed, a wonderful thing, and I have often thought how much better the memory of a photographic plate apparently is than our memory. I use the word "apparently" here purposely, because I am by no means sure that, if we had more carefully trained memories, or, as Shakespeare calls them, "the tablets of our brains," they would not only equal, but would even surpass the most highly sensitive photographic plate that has ever been produced.

When describing the camera obscura, I called your attention to the fact that it would be an easy matter, by placing in the darkened room of the instrument, a sheet of paper covered with any substance sensitive to light, permanently to record on it the minutest details of the image. Now in point of fact, the wonderful invention of photography was the result of actual trials of this character.

At first thought, photography certainly might not seem to be an invention of a very high order. It was known that there are substances that change colour on exposure to light. It would only require, it seemed, the placing of a sheet of paper on the glass directly in the light. But the camera obscura was invented by Baptista Porta, of Naples, as early as 1538. It was known as early as 1777 that light possesses the power of affecting certain compounds of silver. And yet it was not until long afterwards, in 1814, that the great invention of photography was actually made.

Like many other great inventions, this was not made by a single individual. The first discovery in this art may, perhaps, be regarded as beginning in the year 1802, when Josiah Wedgwood, an English potter, and Sir Humphrey Davy, an English philosopher, described a method they had employed for copying shadow pictures, or the profiles of opaque objects, by light acting on paper or leather covered with a small quantity of silver chloride. On exposure to sunlight this material changes in colour from a nearly pure white to a purplish black. The shadow pictures so obtained were, in reality, photographs. They possessed but little value, however, since no means had then been discovered for making them permanent by fixing them; i.e., by dissolving off the silver chloride that had remained unaffected by the light. Unless this was done the photographs were necessarily spoiled by a general blackening of their surfaces when taken into the light.

At a much later date, in 1839, an Englishman, named Fox Talbot, in a paper read before the Royal Society, described a method by means of which pictures thus formed could be fixed by the use of a solution of common table salt. This was a great improvement, but unfortunately the fixing agent employed was imperfect in its actions, so that even these pictures gradually browned or darkened on prolonged exposure to the light.

But before this time a French experimenter, Joseph Niépce of Chalons, after working for some fifteen years in an endeavour permanently to fix the images produced in the camera obscura, described in 1829, a process by which he was able to do this. Moreover, about 1824, another Frenchman, Daguerre, an artist, who had been trying to do the same thing, had opened in the city of Paris an exhibit called the diorama. Daguerre employed the camera obscura to aid him in painting his pictures. He tried for many years to fix permanently the pictures formed in the camera obscura by the action of the light on plates covered with substances that were acted on by light. Niépce and Daguerre finally entered into a partnership and worked together with the idea of more thoroughly solving this important problem.

Before these men had formed their partnership, however, Niépce had invented the following process: Dissolving bitumen or pitch in a solvent liquid, he flowed the solution uniformly over the surface of a metallic plate, and, when dried in the dark, placed the plate in the camera obscura, so that the image of the object was focused on its surface. The action of the light rendered insoluble the portions of the pitch surface on which it fell, so that when the plate was developed by flowing a suitable solvent liquid over its surface, the portions not acted on by the light were removed. In this way a picture remained on the surface of the bitumen in relief, or standing up higher than the portions that had been dissolved. This process, though successful, was objectionable in that the action of light was so feeble that an exposure for several hours was necessary.

Niépce and Daguerre worked together but without any marked success. Niépce died in 1833, but Daguerre, continuing his experiments, at last made a great discovery. By exposing a silver plate to the vapour of iodine, he formed on its surface a uniform and thin layer of iodide of silver, a substance very sensitive to the action of light. This action, however, had long remained unknown because it left no visible traces on the plate.

You can convince yourself of this by asking some one to let you come into the dark room when they are about to develop a photograph. When the plate which has been exposed in the camera is taken out of the plate-holder for development, no traces of an image can be seen on its surface. Some peculiar action has taken place in its sensitised surface, the nature of which is not exactly understood. The picture is invisible, but when the plate is subjected to a process called "development," you will see the picture flash out in a very wonderful manner.

Daguerre, failing to see any image on his silver iodide plate, thought that the light had not affected it. One of these silver plates, that he put in a closet until he could find the time to clean it, recover it with iodide of silver, and use it again, was unintentionally exposed to the fumes of mercury, and these fumes instantly developed the latent picture and thus made it visible to the eyes.

Some people seem to get no little pleasure in the belief that many great scientific discoveries were the results of mere chance. They are apt to cite the discovery of this great principle in photography as an example. This is not at all fair. It is true that Daguerre's discovery was, to a certain extent, accidental, but you must remember that Daguerre had been working for years in this line in an endeavour to find some way of obtaining a visual picture by the action of light. He, therefore, was ready to take the slightest hint that Dame Nature would give him. She gave him the hint and he took it.

Daguerre announced his great discovery in 1839. His first photographs were taken on plates of silver, but in order to decrease the cost, he afterwards employed plates of copper, electro-plated with silver, and afterwards exposed the silvered surface to the action of iodine. Pictures taken by Daguerre's process were called Daguerreotypes. They are positive pictures, and, therefore, possess the disadvantage of permittting only a single picture to be obtained.

Shortly after the announcement of Daguerre's discovery, Fox Talbot, already referred to, made a great improvement in the photographic process by the employment of iodide of silver, fixed in a uniformly thin coating on the surface of a transparent glass plate. The iodide was caused to cling to the plate by covering one of its surfaces with a material that would adhere with considerable force. But since it is not our intention in this Wonder Book to give any more than a general description of the more important facts of photography, and since to a certain extent, most of these processes are based on the original process of Talbot, I will make this description of the art of photography general rather than specific.

There is a great difference between the taking of photographs now and forty or fifty years ago. Then, the photographer was obliged to make his own sensitive plates, and, in fact, to perform all the various processes necessary to produce a picture.

There are two kinds of sensitive plates employed to-day in photography; namely, wet plates and dry plates. Dry plates have come into almost universal use, owing to the fact that after they have been made they can be readily carried from place to place; for, with proper care, they are as good a year or more after they have been made, as they were on the day they were prepared.

Wet plates, on the contrary, are difficult to prepare; require the use of a dark photographic room in the immediate neighbourhood; and must be used shortly after they are made. I think you will understand this better when I describe to you the process required for the production of a wet photographic plate.

The plate of glass that is to be employed for a wet photographic plate must first be thoroughly cleansed. An exceedingly small speck of dirt may ruin the photograph. The plate is then covered with a uniform layer of a liquid substance called collodion, produced by dissolving a variety of gun-cotton in a mixture of alcohol and ether. Thus prepared, collodion is a colourless, transparent liquid. When flowed over the surface of the glass plate, the alcohol and ether rapidly evaporate, leaving a uniform and firmly adhering film of gun-cotton.

Before flowing the plate with the collodion, a certain quantity of iodide or bromide of silver, or sometimes mixtures of both of these substances, are dissolved in it. Before thoroughly dry, the plate is immersed in a bath of nitrate of silver to which a small quantity of common salt has been added. In this way a coating of iodide of silver, or bromide of silver, or a mixture of both of the substances, is formed on the plate. The plate is then set aside to drain, and is afterwards exposed in the camera while in a moist state to the action of light.

It is not difficult to see how inconvenient the wet-plate photographic process must be, when pictures are to be taken at any distance from a dark room, since one must take along a large amount of apparatus necessary to produce the plates in the dark.

After the exposure of the plate it is necessary to bring out the latent image. This is done by the process known as developing, where certain chemical substances are employed, such as salts of iron and pyrogallic acid. The developer acts by reducing to the metallic state those portions of the iodide or bromide of silver that have been acted on by the light. Since the amount of the change that takes place is proportional to the amount of light that has fallen on different portions of the plate, there will be seen on the developed plate a negative picture, or one in which the light portions of the image are reproduced in black, while the dark portions, or those on which little or no light has fallen, remain either but slightly affected, or are even entirely unaffected, so that the plate will remain of the same colour it had before it was exposed to the light. As soon as the development of the plate has gone on to a sufficient degree, the plate is washed in water so as to remove the developer thoroughly and thus check its further action.

Were the plate now exposed to the light, the photographic picture on its surface would be ruined, since it still contains a considerable quantity of the sensitive silver salts that have not been acted on by the light. A process known as fixing must therefore be employed. This is done by washing the plate with a chemical solution known as hypo-sulphite of soda which dissolves and thus removes the unaffected silver salts.

The next step is to wash the plate thoroughly so as to remove the hypo-sulphite. Unless this is done the picture is apt to fade.

The photographic plate thus obtained forms what is called a *negative,* since in it the lights and shades of the natural object are reversed. A negative, however, possesses the great advantage of readily producing a great number of pictures in which the lights and shades are as seen in nature; or, in other words, are positive.

There are various ways in which positives can be obtained from negatives. One of the simplest consists in coating a sheet of paper with a thin film of silver chloride, a chemical substance whose power of turning black on exposure to light is well known. The dried, photographic negative is placed over a sheet of this paper and exposed to light. The portions of the paper immediately under the clear parts of the glass are blackened by the light, while those immediately under the blackened portions of the negative remain white, so that in this way, a positive picture is produced. Of course, as soon as this is done, all the silver chloride that has been unacted on must be removed; that is, the picture must be fixed. This is done by washing it in a solution of hypo-sulphite of soda.

Pictures produced as above are called silver prints. They consist in reality of coatings of metallic silver, spread in different thicknesses over the surface of the paper, thus producing the necessary shading. Since metallic silver readily tarnishes on exposure to the air, it is necessary to subject it to a process called toning. The method generally adopted for this purpose consists in depositing a thin layer of metallic gold over the silver. Since gold does not tarnish on exposure to the air, a toned picture will last for practically an indefinite length of time.

Most of the photography that is carried on out of doors to-day is done by what are called photographic dry plates. These consist of glass plates, one surface of which is covered with a coating of gelatine in a condition known as emulsion; that is, the gelatine has been acted on by a solvent so as to assume the shape of minute globules suspended in the liquid. This gelatine has been rendererd highly sensitive by being mixed with sensitive bromide of silver, and is then spread uniformly in a thin layer over the surface of the glass plate.

There are many processes employed for the preparation of this emulsion by which the degree of its sensitiveness may be varied. I will not attempt, however, to describe them in this book. It is enough to say that dry photographic plates thus prepared can readily be made extremely sensitive.

Sometimes, instead of employing glass for the preparation of dry photographic plates, a long, thin sheet of celluloid, a variety of gun-cotton is used, with a sensitised coating of gelatine spread over its surface. The sheet is tightly rolled and placed in the camera so that a portion may receive the image. When an exposure is made, this portion is replaced by another portion of the roll that has not yet been exposed. Those of you who have worked with cameras of the kodak type, remember how, after you have focused the camera as well as you can on a distant object, and have exposed a portion of the film, you must turn it so as to bring a new portion ready for exposure. In some forms of cameras, such as those employed for taking the successive pictures that are used in moving-picture apparatus, the film is rapidly moved by clockwork.

It is possible to make dry photographic plates or films so exceedingly sensitive that their action is practically instantaneous. With such films, excellent pictures can be taken of waves at the seashore when in the act of breaking; of a yacht that is rapidly moving past the camera;

of a bird while in flight; of a racehorse on the track; or of a rapidly moving express train. Since the films are thin, many dozen separate pictures can be placed on a single roll. This is a matter of great convenience, since a camera, once loaded, can be employed for a considerable time. Moreover, it is not necessary to at once develop such pictures on the film. They can be kept for a long time after they have been taken without injury.

The ferrotype is a form of photograph with which many of you are familiar, although the ferrotype is not as much employed now as it was formerly. In the ferrotype the photograph is taken on the surface of a thin plate of iron covered with black varnish so as to protect the iron plate from the action of the chemical solutions in which it is placed. The sensitised surface of the ferrotype is coated in various ways with sensitive salts, sometimes a wet process being employed, and sometimes a gelatine emulsion being spread over the surface of the plate.

There are a great number of processes called photographic printing processes, whereby it is possible to employ a photographic positive in connection with printer's ink, and so produce an indefinite number of copies. It is possible, also, to make a photographic picture on a lithographic stone and thus produce an indefinite number of pictures by photo-lithography.

CHAPTER XXX

SOAP-BUBBLE COLOURS

Most of you have blown soap-bubbles. If you have not, I would earnestly advise you to begin, no matter how old you may be; for it will give you much information as well as pleasure.

When you first begin to blow a soap-bubble it possesses a good reflecting surface, and, therefore, acts as an excellent convex spherical mirror, which, like all mirrors of this kind, produces amusing and curious contortions in the shapes of its images. As the bubble increases in size, and, consequently, as the thickness of the film decreases, in addition to the curious images, prismatic colours begin to be seen on its surface. At first these are so weak that it is difficult to distinguish them, but as the walls of the soap-bubble film grow thinner the colours become more and more distinct, until, when the bubble becomes large, they rival in brilliancy the colours of either the rainbow, or of the solar spectrum as caused by the passage of sunlight through a prism. Now, it can be shown, as indeed I hope you will be able to understand after reading this chapter, that a soap-bubble film is by no means of uniform thickness at all places. If it were, the same colour would be seen over all parts of its surface. As you know, this is never the case.

A soap-bubble soon breaks, for its life is short. If, however, it is guarded against the causes that tend to break it, its life may be greatly prolonged. Now there are mainly two causes for the breaking or bursting of a soap-bubble. One is its exposure to jarring or sudden blasts of air. The other is the thinning of its film by rapid evaporation. The latter is the chief cause of a high mortality among soap-bubbles; for since its extended surface offers an admirable chance for evaporation, the bubble dries up, or evaporates at its surface, and thus soon becomes so thin as to break.

There is a simple way by means of which it is possible so greatly to increase the life of a soap-bubble that it becomes so to speak a veritable Methuselah among soap-bubbles.

If a soap-bubble, which ordinarily lives a fraction of a minute, can be kept from breaking for four, five, six, or even eight hours, its lifetime will be many times that of an ordinary bubble. Such a bubble would certainly out-Methuselah Methuselah; for he lived only 969 years. Taking the life of a man at present as three score years and ten, or seventy years, we see that Methuselah lived not quite fourteen times as long as the average man. A soap-bubble that was kept from breaking for six hours would live 360 minutes, or 21,600 seconds, as compared with one-quarter of a minute, or fifteen seconds, for the life of an ordinary bubble. So the bubble would have existed 1440 times as long as an ordinary bubble, whereas Methuselah lived only fourteen times as long as the ordinary man.

I am sure you will be interested to know how you can prolong the life of a soap-bubble. It is not at all a difficult matter. You must simply protect the bubble from blasts of air and prevent it from evaporating. In addition to this, you must keep the bubble in as quiet a place as possible, so as to protect it from jarrings. Since my six-hour bubble spent its life in a school-house, where there were about seven hundred boys, I think you may expect to keep a bubble alive at least as long as I did. Of course, to do this, you must get a good variety of soap-bubble liquid, preferably a mixture of good castile soap and glycerine.

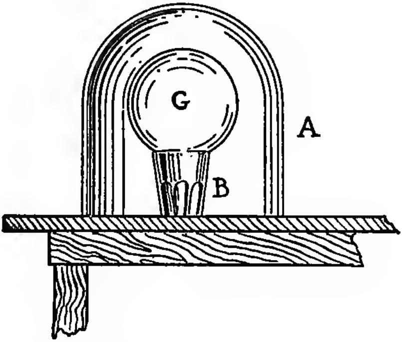


Fig. 107.—An Exceedingly Venerable Soap-Bubble.

And now for the details of the experiment. You will need a large bell-jar A, Fig. 107, although a large candy jar will answer. Place on a table, in as quiet a room as you can, a tumbler B, with the mouth upwards. Select for this purpose a tumbler whose edge is smooth. Blow a good-sized bubble G, and, before it has reached its full size, permit the bottom to come in contact with the moistened top of the tumbler. When the bubble has become fairly large, gently disengage it from the pipe. This requires some skill, but I think you will soon be able to do it. Having previously placed some water on the top of the table, and moistened the inside of the bell-jar A, place it over the bubble as shown. The bell-jar will now protect the bubble from having its life knocked out by draughts of air, and since the air inside the jar will soon become filled with moisture, by the evaporation of water purposely placed inside it, the bubble will be protected from the principal thing that would tend to extinguish it; that is, evaporation. You have now caged your bubble and can watch it grow old.

What will most probably eventually cause the death of the bubble is that the soapy water which forms its film will gradually drain downwards from the top of the bubble to the place where it rests on the edge of the glass tumbler. In this way the top of the bubble will gradually become thinner and thinner and at last will necessarily break.

The colours produced by very thin soap-bubble films are wonderful both in their variations of hue, as well as in their intensity. As the caged bubble grows older, its film becomes thinner, especially at the top, where the most wonderful display of colours is apt to occur. At last, however, when the bubble is nearing its end, it begins to show some of the signs of old age. In the case of a soap-bubble, these signs are especially seen by the colour of its top or head approaching a black. In this way a very aged soap-bubble differs from men and women in whom as you know the approach of old age is indicated by the whitening of the hair. In the case of the soap-bubble, it is by the blackening of the top of the bubble. This blackening is caused by the soap-bubble film becoming so thin at the top that its thickness is somewhere in the neighbourhood of the diameter of a molecule of water.

The colours seen in soap-bubbles are produced in an entirely different manner from those of ordinary coloured fabrics. The material of the soap-bubble film is transparent or colourless, and it is white light that falls on the bubble. What is it then that causes the brilliant display of colours? It is certainly neither the absorption of certain of the rays, nor is it their dispersion as in the case of a prism. It is due to an entirely new cause that has not yet been described; i.e., to the fact that light is produced by wave motion in the universal ether.

If you were asked what would happen if two candles could be lighted so absolutely at the same time, that the ether waves from each candle, moving outward in all directions, would reach the ether situated somewhere between the two candles, so that both sets of waves would simultaneously cause it to move to-and-fro, what would you say? Would the motions and consequently the light at these points be greater or less in intensity than the motions and light at other points? I imagine that most of you would say: "Why, of course, the light would be twice as intense at all points, since if one candle can give out light of a given intensity, then two candles must give out light of twice the intensity." This answer would be correct, provided the distance in which the waves from each of the candles tended to move the ether was the same.

But suppose, owing to the light from one candle moving through a distance sufficiently greater than the light from the other candle, that it would reach the ether between the two candles at such a time that it would try to move the ether in a direction opposite to that in which the other candle was trying to move it, and that these two forces were exactly equal in strength and continued to act for the same length of time. I am sure you can see that then there would be no motion whatever. The waves from one candle would exactly neutralise the waves from the other candle, and since in light the absence of ether motion means darkness, there would be places between the two candles where the light would be entirely absent. At first sight it seems here as if this is a case of one being added to one and producing nothing. It is not, however, but is rather the case of one minus one being equal to zero; that is, one taken from one leaves nothing, which must of course be the case.

Perhaps you will understand this better if I put it in another way. You all know the game of tug-of-war. Now the case of the waves from the two candles trying to move the ether in opposite directions, for equal times, with equal forces, is similar to the tug-of-war. The ether forms the rope; the equal forces oppositely acting for equal lengths of time, are the teams pulling on the halves of the rope. If the teams are exactly matched, the rope does not move.

Without going any further into this subject, I may say if a ray of light R, Fig. 108, of a single colour (say a ray of light produced by burning sodium in an alcohol flame) be permitted to fall on the thin surface of a soap-bubble film A, represented as of varying thickness, a portion of the light 1 will be reflected or thrown off from the upper surface of the bubble, and that a part of the remainder, passing through the film, will be reflected from its lower surface 2, and, after passing through the film, will again emerge at its upper surface at 3 so near 1 that the rays 1 and 3 will endeavour simultaneously to affect the same ether. Now calling the ray reflected from the upper surface the first ray, and the ray which has emerged after passing twice through the film, the second ray, it will be seen that the second ray has passed through a length of path greater than that of the first ray, by a distance, approximately, equal to twice the thickness of the film, and has, therefore, been retarded back of the first ray by this distance. If now this retardation is equal to the half of a wave length of light, or three-halves of a wave length, or any odd number of half wave lengths, then the two rays will neutralise each other, since they will attempt to move the ether in exactly opposite directions for equal periods of time. Consequently, no light will be seen at these points. At such portions of the film, however, where the retardation is equal to a whole wave length of yellow light, or two whole wave lengths, the first and second ray will simultaneously attempt to move the ether in the same direction, and a band of bright yellow light will result. Now what is true of yellow light is true of any of the coloured rays of the spectrum, only the position where the rays can extinguish or augment each other will vary with the different coloured light.

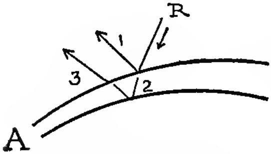


FIG. 108.—A SOAP-BUBBLE FILM.

It was Sir Isaac Newton who first studied the cause of soap-bubble colours. He did this by means of a plano-convex lens whose curved surface was rested against a flat sheet of glass. The film of air between the two plates gradually increased in thickness from the centre outwards. When a beam of sunlight was permitted to fall on such a plate, a series of rings, of the colours of the solar spectrum, were seen arranged around the point where the curved surface touches the flat glass. Here, as you may be able to understand, the successive circles of colour were due to the fact that each of the coloured rays produced an increase in intensity of light at places where the retardation of one ray was equal to a whole wave length or any number of whole wave lengths, and that these colours, falling in regular order according to the increased thickness of the film, produced the coloured prismatic rings.

Colours produced in this manner are said to be produced by the interference of light. Such colours are also produced in many other ways. For example, the colours seen when films of oil or tar float on water are soap-bubble colours. So, too, are the colours produced by films of oxide of iron on the surfaces of articles of tempered steel. So, too, curiously enough, are the brilliant colours seen in the wings of certain insects; the iridescent colours of rainbow coal and some other minerals, and on a great variety of other substances, such as mother-of-pearl.

CHAPTER XXXI

RAINBOWS AND OPALESCENCE

ALTHOUGH the subject of rainbows was discussed in "The Wonder Book of the Atmosphere," yet, since we have now studied the general principles of light, it may be well again to discuss it here at somewhat greater length.

The rainbow may properly be regarded as among the most beautiful and wonderful of all natural phenomena. It is produced by a variety of causes and is in reality quite complex. While I shall make no attempt to give a full description of its causes, yet I can tell you now much about it that I am sure you can understand, and so form some idea of its complexity as well as its beauty.

Of course you all know that rainbows are only seen when raindrops are falling, and are due to the rays of light entering your eyes after having passed through the drops. In order to see a rainbow, you must stand with your back to the sun directly facing the falling drops. Under these circumstances you may see an arc or bow spanning the heavens containing the colours of the solar spectrum. The centre of this bow is situated where the shadow of your eye would fall on the sky, provided it were possible for such a shadow to be formed. The size, therefore, of the rainbow increases as the sun sinks lower and lower in the sky.

Generally speaking, when the rays of sunlight fall obliquely on raindrops, they enter the drops and, while passing through them, are refracted. Then, on reaching the back of the drops, they are reflected and again refracted. In other words, the rays that enter the drops are twice refracted and once reflected. During this refraction they also undergo dispersion or separation into their prismatic colours. They emerge, therefore, from the drop, separated into their different coloured rays just as they do after having passed through a prism.

When these coloured rays emerge from the drops they are divergent, and since the raindrops through which they have passed are situated at fairly great distances from the observer's eyes, they reach the eyes so decreased in intensity, owing to the space over which they have been spread, that they are too feeble to produce any marked effects of colour.

It is not all the rays, however, that are divergent and, therefore, unable to affect the eyes. A certain proportion; i.e., those produced by the rays of white light that strike the drop at a certain angle, emerge as parallel coloured rays, and these rays, like those that are passed through a Fresnel light-house lens, have not decreased in intensity and, therefore, are capable of impressing their colours on the eyes.

Owing to the fact that the coloured rays are divergent, it will be impossible for one observer to see any more than a single collection of rays from a given set of drops. For example, red rays can only be seen that have been formed by the light which passes through raindrops occupying a certain angular position as regards the sun and the eye of the observer. Of course any drops that occupy this angular position will also have their red rays enter the eye of the observer. It can be shown that these drops would lie along portions of a circle at the centre of which the eye of the observer is situated. The observer would, therefore, see an arc or bow of red light only, although undoubtedly other coloured rays have entered his eye, which, however, have been so weakened by divergence that they failed to produce any effect of colour.

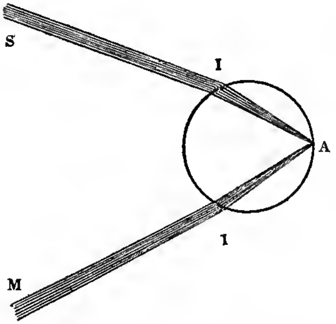


FIG. 109.—ACTION OF RAIN DROP ON BEAM OF SUNLIGHT.

But other raindrops also produce parallel emergent rays, and since different coloured rays of light are differently dispersed, the drops producing the other coloured rays will be situated on different circles all of which, however, will have the eye of the observer in their centre.

An arc or bow will, therefore, be seen projected on the sky, with the eye of the observer as a centre, that will contain all the colours of the prismatic spectrum, and will, moreover be arranged in the order of their refrangibility.

In Fig 109 is shown the position of a beam of light S I, coming from the sun and falling on a raindrop at I. This beam passes through the drop and is reflected as shown at A and emerging takes the path I′ M. It is, therefore, twice refracted and once reflected. Since while it is undergoing refraction it is separated or dispersed into its prismatic colours, it emerges in the form of the colours of the spectrum. Now I, is that part of the drop where several parallel rays passing into the drop while undergoing dispersion as well as refraction emerge parallel to their original direction, and, therefore, are able to affect the eye of the observer.

Tyndall thus describes in simple language the cause of the rainbow:

"The rainbow is in fact a spectrum, in which the raindrops play the part of prisms. The width of the bow from red to violet is about two degrees. The size of the arc visible at any time manifestly depends upon the position of the sun. The bow is grandest when it is formed by the rising or the setting sun. An entire semicircle is then seen by an observer on a plain, while from a mountain top a still greater arc is visible."

In the rainbow the order of the colours is such that the red is at the top of the bow and the violet below. This bow is called the primary rainbow, in order to distinguish it from a fainter bow called the secondary rainbow, that is formed above the primary bow as shown in Fig. 110. The secondary bow is produced by rays of light that entering at the bottom of the raindrop undergo two reflections from the back of the drop and two refractions at the surfaces. Since the beam is reversed by this double reflection, the order of the colours of the secondary bow will be reversed; i.e., the violet rays are at the top of the bow, and the red are below. This double reflection of the light also greatly weakens its intensity, so that the secondary bow is fainter than the primary. On some rare occasions a third bow is seen below the primary bow. Its colours, however, are generally very faint.

Rainbows can of course be caused by particles of water that are distributed through the air in any way, whether as falling raindrops, or as the spray from waterfalls, by waves, or breakers during stormy weather, or by being thrown into the air from a jet or nozzle.

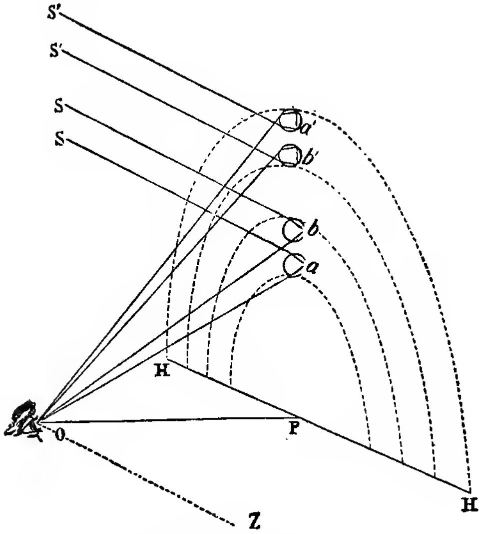


FIG. 110.—CAUSE OF THE PRIMARY AND SECONDARY RAINBOWS.

As we have seen in some of the preceding chapters, the white light of the sun may produce colour in the bodies on which it falls in several ways. In opaque coloured bodies some of the rays are absorbed so that those which are thrown off from the surface are necessarily coloured. In transparent coloured bodies some of the rays are absorbed so that the remaining rays that are transmitted must necessarily be coloured. On the passage of light through a prism the separate coloured rays are so differently refracted by dispersion that when they emerge from the prism they are too far apart to simultaneously affect the eye and therefore appear coloured. And then, again, we have soap-bubble colours that are produced by the interference of the rays of light.

There yet remains to be explained another method of producing colour that is called opalescence, which takes its name from the peculiar colours produced in a variety of mineral known as the opal, a variety of quartz.

The colours of opalescence are produced in a manner entirely different from any of the before mentioned ways. The opal owes its display of colours to the presence of a great number of very small reflecting particles that are distributed through the solid transparent material of the mineral. When sunlight falls on an opalescent substance, owing to the small size of the reflecting particles, the blues and violets are reflected from them, so that the substance throws back the reflected light. The rest of the light either passes through or is partially absorbed.

I am sure it will interest you to know that the blue colour of the sky is due to opalescence. In this case, however, the minute reflecting particles are distributed, not through a solid mass of a transparent solid, as in the opal, but through a mass of transparent air. These sky particles are so small that they are capable of reflecting the blue rays of light only, thus giving to the sky its characteristic colour. The other coloured rays are but little absorbed and pass through the air as can be seen from the fact that the transmitted light, coming from the sun, gives to the sun a yellow colour, when the number of sky particles is small, and a deep red colour when the number is great. The latter, as you know, occurs when the air is filled with smoke particles as it is apt to be during the time of year known in our latitude as Indian summer. It also occurs when finely divided volcanic ashes are suspended in the air, as was the case during the explosive eruptions of Kra̍katoa and other volcanoes.

The blue colour of the sky is, therefore, a phenomenon of opalescence, and is due to the presence of a great number of what might be called sky particles consisting of numerous exceedingly minute particles of floating dust or other matter that are so small as to be capable of reflecting the very short wave lengths of light only; i.e., the blues and the violets. The depth of the colour increases with the decrease in the size of the particles as well as with a decrease in their number. After a heavy rain, when the face of nature has been as it were washed, the blue colour deepens, and, indeed, in very high mountain regions, often takes on a colour almost as deep as an indigo blue. On the other hand, when the number and size of the particles increase, especially when the particles consist of minute drops of water, the air assumes a hazy or whitish appearance, since then nearly all colours of light are reflected.

Any transparent medium will appear of a bluish colour if small reflecting particles are distributed throughout it. As you well know, very clear water, when deep, takes on a marked bluish tint. When the light enters the eye after it has been reflected from the great number of very exceedingly small particles that are spread through the water, it takes the characteristic blue colour because generally blue light only is reflected from these small particles. Glacial ice show a similar phenomenon. I have seen, in the glaciers on the Alps, while standing at an edge of a deep fissure, or crevasse, and looking down its vertical walls, the wonderful blue colour that is assumed by the ice.

You have all probably heard of sky-blue milk. This is a name given in pleasantry to milk that has been too greatly diluted with water; for, if a large quantity of water is mixed with milk, a bluish opalescence results, the particles of milk being scattered in exceedingly minute drops throughout the water.

There is a simple experiment you can try in opalescence to illustrate the blue colour of the sky. Eau-de-Cologne, that is, ordinary cologne water, consists of pure alcohol in which has been dissolved various odorous resins, gums, and essential oils. If a drop or two of cologne be permitted to fall in a large glass jar filled with clear water, the resins, gums and oils being deprived of their solvent alcohol, are thrown down in the shape of a fine cloud of exceedingly small particles. This cloud, when seen by reflected light, assumes the blue colour of the sky. In trying this experiment, it is best to permit a single drop of the cologne to fall into the water, and, if this does not produce the desired results, to follow it by a second drop. If too many of the resinous or oily substances are placed in the water, it will take on a milky appearance, owing to the particles being too great in number and of too large size.

There is another instance of a blue colour produced by opalescence, when the smoke of a fire is seen against a dark background, such, for example, as the foliage of a tree. Here, the smoke appears of a distinct blue color. You may have noticed this while out on a picnic. In a similar manner, the smoke of a cigarette or cigar, when in small quantities, takes on a blue colour, but when thrown out by the smoker in too large volumes, it appears of a whitish tint.

CHAPTER XXXII

POLARISED LIGHT

BEFORE closing The Wonder Book of Light, I wish to tell you a little about some complex matters in optics, which, though far too difficult to discuss fully in a book of this scope, yet may be made tolerably plain.

There is a variety of transparent mineral known as calcspar, or carbonate of lime, that possesses the curious property of causing a single ray of light, passing through it in a certrain direction, to be broken up into two separate rays that take different paths. Both of these rays undergo refraction. In order to distinguish this peculiar kind of refraction from ordinary refraction, it is called double refraction. This variety of calcspar is quite transparent. If objects are looked at through the mineral, they will, in most positions, appear double, since each of the rays of light into which the single ray is split up produces a separate image.

Now the two rays, into which the single ray of light is divided by double refraction, differ markedly in many respects from ordinary light, and this is due to the fact that they are polarised. In other words, these rays possess different properties in different directions, just as a magnet possesses different properties at its opposite ends or poles.

Ordinary light is produced by ether waves in which the ether moves in directions at right angles to the direction in which the ray is passing. Now, while in ordinary light, all these vibrations take place at right angles to the path of the ray, yet the successive to-and-fro motions occur in paths that are inclined to one another. I know this is hard to understand, but the successive paths, in which the ether moves, are something like the steps of a circular staircase. All the steps are horizontal; that is, all are at right angles to the direction of the vertical support about which they wind, but the successive steps are inclined to one another.

In a ray of ordinary light, the vertical support of the staircase may be taken as the direction in which the ray is advancing, while the successive steps represent the successive ether paths. One path, say that near the bottom of the flight, is in the direction of the bottom step. The next, is in the direction of the next step, and so on throughout the entire flight from the bottom to the top.

In polarised light, however, while the ether paths are also all at right angles to the direction in which the ray is moving, yet all the successive paths are parallel to one another.

As already mentioned, the two rays into which a single ray of light is broken by double refraction, consist of polarised light, and, like all polarised light possess many peculiarities that are quite different from those of ordinary light.

There are a number of ways in which ordinary light can be polarised. One of these was discovered by Malus, in 1808, while looking at one of the windows in the Palace at Luxembourg, through a prism of a double refracting substance. He noticed, when the prism was rotated or turned in front of his eye, that in certain positions one of two images produced by the double refracting substance completely disappeared, but that if he continued the rotation, it reappeared, while the other image disappeared. Without going any further into this difficult matter, I would say that the alternate disappearance and reappearance of the images of the window was due to the polarisation of the light reflected from the window, and, that investigations made by several scientific men, resulted in the discovery that under certain circumstances the light reflected from any surface is polarised.

Light may also be polarised by its passage through certain minerals, such as plates of tourmaline. Light is also polarised by single refraction, provided the light falls on a reflecting surface at such an angle of incidence that the reflected ray is thrown off at right angles to the path taken through the material by the refracted ray. In this case the reflected ray is also polarised.

Any device for polarising light is called a polariser. Any device for detecting the presence of polarised light is called an analyser.

One of the simplest polarisers consists of slices, cut from a six sided prism of a mineral called tourmaline at right angles to its greatest length. Different specimens of tourmaline vary in transparency from those that are completely opaque, to those that are partially transparent. When thin slices of such crystals are obtained, the light that passes through them is completely polarised, so that such a section forms a polariser.

Now any polariser may also act as an analyser; for, if two such tourmaline polarisers, such as *b a,* are placed as shown in Fig. 111 the light is polarised by its passage through *a,* and this no matter how far *a* may be separated from *b.* If, however, *b* is slowly rotated it will be found that the light from *a* no longer passes freely through it; for, when a slight inclination is reached, as shown at *b′ a′*, some of the light of *a* is cut off, and when the two plates occupy the positions shown at B A, the light polarised by its passage through *a* is completely opaque to the tourmaline analyser B.

It is always true that light, polarised by its passage through any polariser, can only pass through another polariser when that polariser occupies a certain position, so that when an analyser is held between the eye and a beam of polarised light, there will be formed two positions in which the light freely passes through it, and two positions, at right angles to the former, where no light whatever is able to pass. Although polarised light cannot be distinguished from ordinary light by the unassisted eye, yet it can, therefore, be detected readily by the use of an analyser. Examined in this way, the light from certain parts of the blue sky can be shown to be partially polarised.

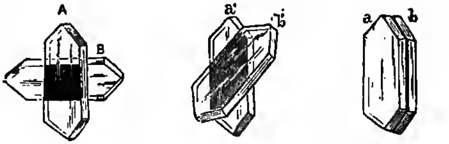


Fig. 111.—Tourmaline Polarisers and Analysers.

A much better form of polariser is the Nicol's prism.

This consists of a prism, Fig. 112, formed of a piece of doubly refracting calcspar, about an inch in height and a third of an inch in breadth, that is sawn or cut in two along the diagonal plane *bdac,* as shown. The two halves are then cemented together in their former position by means of a transparent cement known as Canada balsam. In this way the prism is in no wise changed from its original condition except that a thin slice of Canada balsam has been introduced into its mass at the diagonal cut. Now a result of this construction is that the Nicol's prism possesses the property of transmitting only one of the two rays into which a ray of ordinary light on passing through it is divided; for, on meeting the first surface of the Canada balsam, one of these rays is totally reflected, and passes out at the side of the crystal, while the other ray passes through the Canada balsam and emerges at the end of the prism completely polarised.

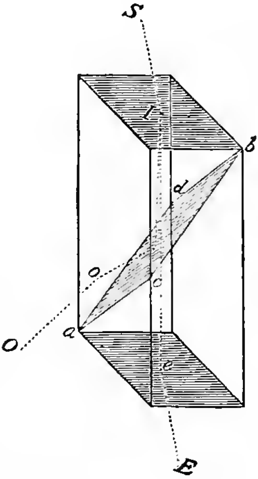


FIG. 112.—NICOL'S PRISM.

This form of polariser is more frequently employed than any other since all the light passing through it is completely polarised; and, owing to the transparency of the calcspar it permits more light to pass through it than does a plate of tourmaline.

There are a variety of curious effects produced by the passage of polarised light through different transparent substances. Among these are the exceedingly beautiful colours that are produced by the interference of the rays of polarised light on their passage through various transparent double-refracting media. These interference colours are produced in a manner not unlike that explained in the production of soap-bubble colours.

Other sets of phenomena are caused by the passage of polarised light through various transparent substances such as certain prisms of quartz or rock crystal. Some varieties of quartz possess the curious property of causing a beam of polarised light, while passing through them, to rotate or turn the plane in which the light has been polarised. This property is known as rotary polarisation. While a beam of polarised light is still polarised after its passage through a crystal of quartz, yet when it emerges from the crystal, the plane in which it has been polarised is rotated or changed.

Some substances possess the power of rotating the plane of polarisation to the right hand, or are said to possess right-handed rotary polarisation. Others turn it to the left, or have left-handed rotary polarisation. Strange to say, some substances, like quartz, are able, in certain specimens, to rotate the plane of polarisation to the right, and, in other specimens, to rotate the plane of polarisation to the left.

Polarised light is employed to a considerable extent in sugar refineries for the purpose of making a rapid analysis of the quantity of sugar present in a solution. There are two kinds of sugar, one of which, like loaf-sugar, is crystallisable, and the other, like molasses, is uncrystallisable.

Now it happens that these two kinds of sugar rotate the plane of polarised light in different directions, so that by the use of an apparatus known as the saccharimeter it is possible, by simply causing a beam of polarised light to pass through a clear solution containing both kinds of sugar, to tell, by the appearance of certain colours, not only the kind but also the amount of sugar present.

With this I must close The Wonder Book of Light. Many of the subjects I have discussed are very difficult, and some of you may at times have found it hard to follow me. I feel sure, however, that most of you cannot have failed to obtain considerable valuable information from what you have read, and even though, now and then, the matters have been too difficult, yet it will not hurt you to put the book aside for a year or so, when you can again read it to see if you cannot then understand what now bothers you.

THE END