A LIST

OF THE

CHIEF MEMOIRS

ON THE

PHYSICS OF MATTER

COMPILED BY

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PREFACE.

The following list of Physical Memoirs is intended to serve as a guide to the student or teacher wishing to acquire a general knowledge of certain branches of Physics. The limitation of number thus imposed makes the choice in many cases somewhat arbitrary; but it is hoped that the five hundred chosen include most of the work of permanent value in the section of Physics considered, and may serve also as a basis of reference to those who wish to specialize on a particular subject. Preponderance has been given to recent papers, as it is less easy to get references to them. The Journals have been consulted down to the end of 1892.

The subject dealt with is 'Physik der Materie,' as opposed to Physics of the Ether,—that is Heat, Elasticity, Sound, &c. Papers of a purely mathematical character, on dynamics, elasticity, waves; of a physiographical character;

and papers on the allied subjects—Radiation, Chemical Physics, Crystallography, are only mentioned in a few cases of exceptional importance.

Such a compilation necessarily lays itself open on all sides to charges of omission and of bad judgment from those who are better acquainted with each branch; the Author can only hope that any using this pamphlet will send him such corrections and suggestions as may occur to them.

FIRTH COLLEGE, SHEFFIELD,
January 1894.

P.S. The principal memoirs published in 1893 have been inserted during the printing.

CONTENTS.

EXPLANATION OF REFERENCES.

Of the numbers following the name of a journal, that in darker type indicates the number of the volume; the two following, the first and last pages; after that, in brackets, the year. When a number in brackets precedes the volume number, it refers to the series. The memoirs quoted are nearly all in their original form: reprints and translations are so noted: abstracts (such as those in the Beiblätter to 'Wiedemann's Annalen' and the 'Fortschritte der Physik') are often of use; but as they can readily be found from the author's name and date of the paper in question, they are not given here, except in one or two cases where the original is not in English, French, or German.

The Journals quoted from are given in the list below. In addition are a few special reports (*e. g.* those of the 'Challenger' Expedition, of the Bureau International des Poids et Mesures) and books.

Ann. Chim. Phys. Annales de Chimie et de Physique. Paris: G. Masson. 8vo. Three volumes yearly, in monthly numbers; the present is the sixth series, begun in 1884. Each series usually lasts ten years.

Ann. Sci. de l'École Norm. Annales Scientifiques de l'École Normale Supérieure, publiées sous les auspices du Ministre de l'Instruction Publique par un comité de rédaction. Paris: Gauthier-Villars. 4to.

Arch. de Genève. Bibliothèque Universelle et Revue Suisse. Archives des sciences physiques et naturelles. Lausanne: Bridel. 8vo.

Arch. Néerland. Archives Néerlandaises des sciences exactes et naturelles, publiées par la Société Hollandaise des Sciences à Harlem. Haarlem: les héritiers Loosjes. 8vo.

Beibl. Beiblätter zu den Annalen der Physik und Chemie. Leipzig: Barth. 8vo. One volume yearly, in monthly parts; commenced with the new series of the Annalen, in 1877.

Ber. Berichte der Deutschen chemischen Gesellschaft. Berlin: Friedländer und Sohn. 8vo.

Berl. Sitzber. Sitzungsberichte der Königl. Preussischen Akademie der Wissenschaften zu Berlin. Berlin: Georg Reimer. Lex. 8vo. One volume yearly, in parts. Called Monatsberichte previous to 1882.

Bull. Ac. Belg. Académie Royale de Belgique. Bulletins des séances de la classe des sciences. Bruxelles: F. Hayez. 8vo. Two volumes yearly, in parts.

C. R. Comptes Rendus hebdomadaires des séances de l'Académie des Sciences. Paris: Gauthier-Villars. 4to. Two volumes yearly, in weekly parts; volumes for 1892 are 114 and 115.

J. C. S. The Journal of the Chemical Society of London. London: Gurney and Jackson. Two volumes yearly, numbered consecutively, one of transactions and one of abstracts.

J. de Phys. Journal de Physique théorique et appliquée, fondé par J. Ch. *d'Almeida.* Paris: au Bureau du J. de Phys. 8vo. One volume yearly, in monthly parts. The present is the third series, begun in 1892; each series lasts ten years.

J. f. Prakt. Chem. Journal für praktische Chemie; neue Folge hrsg. von Ernst von Meyer, gegründet von O. L. *Erdmann.* Leipzig: Barth. 8vo.

Leipz. Ber. Berichte über die Verhandlungen der Königlich Sächsischen Gesellschaft der Wissenschaften zu Leipzig. Mathematisch-physikalische Classe. Leipzig: Hirzel. 8vo.

Lieb. Liebig's Annalen der Chemie. 8vo. Three vols. a year.

Mém. de Belg. Mémoires de l'Académie Royale de Belgique. Bruxelles: F. Hayez. 4to.

Mém. de Paris. Mémoires de l'Académie des Sciences de l'Institut de France. Paris. 4to.

Mém. Sav. étrang. Mémoires présentés par divers Savants à l'Académie des Sciences de l'Institut de France, et imprimés par son ordre. Paris. 4to.

Nature. Nature: a weekly illustrated journal of science. London and New York: Macmillan and Co. Volumes begin in May and November.

Ostw. Zeitschrift für physikalische Chemie. Hrsg. v. W. *Ostwald* und J. H. van't Hoff. Leipzig: Engelmann. One vol. yearly, in 12 parts.

Pflüger Archiv. Archiv für die gesammte Physiologie. Hrsg. von E. F. W. *Pflüger.* Bonn: Strauss.

Phil. Mag. Philosophical Magazine and journal of science. London: Taylor and Francis. 8vo. Two volumes yearly, in monthly parts. The present is the fifth series, the volumes for 1892 being 33 and 34.

Phil. Trans. Philosophical Transactions of the Royal Society of London. London. 4to. One volume a year. The volume for 1892 is No. 183; but an extra volume is inserted between 1877 and 1878, altering the numbering. The earlier volumes are divided into numbered parts, but as these are paged consecutively they are not mentioned below. The later volumes are divided into A and B; all the physical papers will be found in part A.

Pogg. See Wied.

Proc. Amer. Acad. Proceedings of the American Academy of Sciences and Arts. Boston. One volume a year.

Proc. R. S. Proceedings of the Royal Society of London. London: Harrison and Sons. 8vo. Two volumes a year, in numbers.

Rep. Brit. Ass. Report of the meeting of the British Association for the Advancement of Science. London: John Murray. 8vo. Bears the date and place of meeting, but published the year after.

Rep. d. Phys. Repertorium der Physik. Hrsg. von F. *Exner.* München: Oldenbourg. Lex. 8vo. One volume yearly, in monthly parts. Formerly edited by *Carl.*

Sill. The American Journal of Science. Editors, J. D. and E. S. Dana and B. *Silliman.* New Haven, Conn.: J. E. and E. S. Dana. Two volumes yearly, in monthly parts. The present is the third series, the volumes for 1892 being 43 and 44.

Trans. Connecticut Acad. Transactions of the Connecticut Academy of Arts and Sciences. New Haven.

Trans. R. S. E. Transactions of the Royal Society of Edinburgh. Edinb. 4to.

Wied. Annalen d. Physik und Chemie. Unter Mitwirkung der Physikalischen Gesellschaft zu Berlin, und insbesondere des Herrn H. von Helmholtz, hrsg. von G. und E. *Wiedemann.* Leipzig: J. A. Barth. 8vo. Three volumes yearly, in monthly parts; with one volume of 'Beiblätter' (*q. v.*). The present series began in 1877, the volumes for 1892 being 45, 46, 47. The preceding series was edited by J. *Poggendorff*, and is quoted as *Pogg.*

Wien. Ber. Sitzungsberichte der mathematisch-naturwissenschaftlichen Classe der Kaiserlichen Akademie der Wissenschaften. Wien: C. Gerold's Sohn. One volume yearly, in parts (previous to 1889 two vols.). Divided into sections I., II. *a*, II. *b*, III., the physical papers being in II. *a* (formerly in three sections, physical papers in section II.).

Zs. f. Instrumentenk. Zeitschrift für Instrumentenkunde. Berlin: J. Springer. One volume yearly.

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GENERAL PHYSICS.

A. Dynamical Principles.

For a discussion on the statement of the dynamical laws, see Thomson and Tait's 'Natural Philosophy,' vol. i. ch. 2, and

1. Mach, E. 'Die Mechanik in ihrer Entwickelung.' Leipzig, 1883. (Translated by T. J. McCormack. Chicago and London, 1893.)
2. Streintz, H. 'Die physikalischen Grundlagen der Mechanik.' Leipzig, 1883.
3. Thomson, J. Proc. R. S. E. **12**. 568–578, 730–742 (*84*).
4. Tait, P. G. Proc. R. S. E. **12**. 743–745 (*84*).
5. Lange, L. Leipz. Ber. **37**. 333–351 (*85*).
6. Muirhead, R. F. Phil. Mag. (5) **23**. 473–489 (*87*).
7. Lodge, O. Phil. Mag. (5) **19**. 482–487 (*85*). "Identity" of energy.

Also a less controversial paper by

8. Wien, W. Wied. **45**. 685–728 (*92*). Mathematical treatment of the localisation of energy: application to hydrodynamics, elasticity, and electricity: relation to the law of entropy.

Some other papers of general dynamical interest are:—

9. Thomson, Sir W. Phil. Mag. (5) **32**. 375–382, 555–560 (*92*). Periodic motion of a conservative system: general considerations of stability.

10. Kelvin, Lord. Phil. Mag. (5) **33**. 291–299 (*92*). Dissipation of energy in the light of the Kinetic theory.

11. Natanson, L. Phil. Mag. (5) **34**. 51–54 (*92*). Remarks on the preceding.

Also

12. Maxwell. Phil. Mag. (4) **40**. 421–427 (*70*); or Collected Papers, vol. ii. p. 233. On hills and dales. Geometry of contour-lines; maxima and minima, &c.

B. Dynamical Explanation of the Second Law of Thermodynamics.

13. Boltzmann. Wien. Ber. **53**. 195–220 (*66*).

14. ——. Wien. Ber. **63**. 712–732 (*71*).

15. ——. Pogg. **143**. 211–230 (*71*). Note on his own and Clausius' papers.

16. Clausius. Pogg. **141**. 124–130 (*70*). Theorem of the virial.

17. ——. Pogg. **142**. 433–461 (*71*). Application of the above to the second law.

18. ——. Pogg. **144**. 265–274 (*71*). Reply to Boltzmann.

19. ——. Pogg. **146**. 585–591 (*72*). Remarks on Szily's paper.

20. ——. Pogg. **150**. 106–130 (*73*). Further observations.

21. Loschmidt. Wien. Ber. **59**. 395–406 (*69*).

22. Szily. Pogg. **145**. 295–302 (*72*).

23. ——. Pogg. **149**. 74–86 (*73*).

24. Grinwis. Arch. Néerl. **19**. 461–478 (*84*). Extension of the virial theorem.

25. Helmholtz, H. von. Berl. Sitz. 1884, pp. 159–177, 311–318. Theory of monocyclic systems: systematic development.

26. Boltzmann. Wien. Ber. **90**. 231–245 (*85*). Elucidation of preceding.

27. Poincaré. C. R. **108**. 550–553 (*89*). Contends that Helmholtz's reasoning is not applicable to irreversible processes.

28. Larmor & Bryan. Rep. Brit. Ass. 1891, pp. 85–122. Critical review of the present state of the question.

29. Thomson, J. J. 'Applications of Dynamics to Physics.' London, 1888: Macmillan. Contains a novel treatment of the question, first given in Phil. Trans. **176**. 307–342 (*85*); **178**. 471–526 (*87*).

C. Theory of Dimensions.

30. Maxwell. Proc. Lond. Math. Soc. **3**. 224–239 (*71*); or Collected Papers, vol. ii. p. 258. Mathematical classification of physical quantities.

31. Budde. Wied. **20**. 161–166 (*83*). Reduction to one fundamental unit by the use of electromagnetic constants.

32. Rücker. Phil. Mag. (5) **27**. 104–114 (*89*). On "suppressed" dimensions.

33. Williams, W. Phil. Mag. (5) **34**. 234–271 (*92*). Relation of dimensions of physical quantities to directions in space.

34. Abraham, H. J. de Phys. (3) **1**. 516–526 (*92*). On the varying dimensions of the same unit. With a very full bibliography of the subject.

D. Measures.

On the theory of measurements, see Thomson and Tait's 'Natural Philosophy,' vol. i. ch. 4. A few papers of interest are :—

35. Macé de L'Epinay. Ann. Chim. Phys. (6) **10**. 68–84, 170–199 (*86*). Measurement of lengths in wave-lengths by means of Talbot's bands. Determination of the size and density of a piece of quartz.

36. Lippmann. C. R. **104**. 1070–1074 (*87*). On an electrical time-unit.

37. Michelson & Morley. Sill. (3) **38**. 181–186 (*89*). On the practical use of the wave-length as a unit.

37 *a*. Michelson, A. A. C. R. **116**. 790–794 (*93*). Preliminary notice on a comparison of the metre and the wave-length of cadmium.

SPECIAL PHYSICS. Molar Theory.

GRAVITATION.

E. Theory of Gravitation.

38. Isenkrahe. 'Die Räthsel der Schwerkraft.' Braunschweig, 1879: Vieweg.

39. Odstrčil, J. Wien. Ber. **89**. 485–490 (*84*). Gravitation viewed as transmission of energy through the ether.

F. Measurement of Constant.

40. Cavendish. Phil. Trans. **88**. 469–526 (*1798*). By torsion-balance.

41. Reich. C. R. **5**. 697–700 (*37*).

42. Baily. Phil. Mag. (3) **21**. 111–121 (*42*).

43. Airy. Phil. Trans. **146**. 297–357 (*56*). By variation of "g" in interior of earth.

44. Cornu & Baille. C. R. **76**. 954 (*73*).

45. —— ——. C. R. **86**. 571–574, 699–702, 1001–1004 (*78*).

46. Jolly. Wied. **5**. 112–134 (*78*). By common balance.

47. ——. Wied. **14**. 331–355 (*81*). By common balance.

48. Poynting. Phil. Trans. **182**. 565–656 (*81*). By common balance.

49. Wilsing, J. Publikat. d. Astrophys. Observ. zu Potsdam. **6**. 35–127 (*87*); **6**. 133–191 (*89*). (Published separately by Engelmann, Leipzig.) Determination of gravitation constant by pendulum.

49 *a*. Berget, A. C. R. **116**. 1501–1503 (*93*). Measurements with a mercury-column differential gravimeter. Determination of constant by attraction of a lake.

G. Measurement of Terrestrial Gravity.

50. v. Oppolzer. Zs. für Instrumentenkunde, **4**. 303–316, 379–387 (*84*). Report on present state of the subject (from the Generalber. d. Europäischen Gradmessung).

51. Darwin, G. H. & H. Rep. Brit. Ass. 1881, pp. 93–126. Instrument for measuring small variations in direction of gravity.

52. Thomson, W. Proc. R. S. E. **13**. 683–686 (*87*). Spring-balance to measure "g."

HEAT.

H. Thermometry.

The exact use of mercury thermometers and their comparison with the air and hydrogen thermometers has been the subject of much study of late years. The best work is contained in the 'Travaux et Mémoires du Bureau International des Poids et Mesures,' vols. 1, 5, 6, and 7. There are useful abstracts :—

53. Guillaume. J. de Phys. (2) **6**. 228–238 (*87*).

54. ——. J. de Phys. (2) **7**. 419–430 (*88*).
Similar work has been done by the Normal-Aichungs-Kommission.

55. Foerster, W. Metronomische Beiträge. No. 3. Berlin, 1881. Includes a comparison with the absolute scale.

Other papers are—

56. Rowland, H. Proc. Amer. Acad. **15**. 75–200 (*80*). Part of a memoir on the mechanical equivalent. Includes a comparison with the absolute scale.

57. Ramsay & Young. J. C. S. **47**. 640–657 (*85*). Means of obtaining constant and known temperatures.

58. Callender. Phil. Trans. **178**. 161–230 (*87*). Use of electrical resistance thermometers and comparison with the air-thermometer.

59. ——. Phil. Mag. (5) **32**. 104–113 (*91*). Use of electrical resistance thermometers and comparison with the air-thermometer.
Comparisons between the air-thermometer and absolute scale are also given in the 'Encyclopædia Britannica' (9th edit.), "Heat" (Lord Kelvin), and in Ruhlmann's 'Heat,' vol. i. p. 550.

60. Guillaume. Arch. de Genève, **20**. 396–409 (*88*). Production and measurement of low temperatures.

I. Mechanical Equivalent of Heat.

Historical interest attaches to the early work on this subject, of which the chief :—

61. Rumford. Phil. Trans. abridged, **18**. 278–287 (*1798*). On the heat excited by friction.

62. Mayer, J. R. Lieb. Ann. **42**. 233–240 (*42*); or Phil. Mag. (4) **24**. 371–377 (*62*) (translation). Remarks on the forces of inorganic nature.

63. ——. C. R. **27**. 385–387 (*48*). Note on above.

64. JOULE. Phil. Trans. **140**. 61–82 (*50*). Long the standard determination.

65. HELMHOLTZ, H. VON. 'Ueber die Erhaltung der Kraft.' Berlin, 1847. (Separate publication.) Reprinted in his Collected Papers, vol. i. pp. 12–75.

Reference should also be made to Clausius' collected papers on the Theory of Heat, vol. i.

Of recent determinations the best are

ROWLAND, H. (*loc. cit.* No. 56), which includes a summary of the earlier work.

66. MICULESCU. Ann. Chim. Phys. (6) **27**. 202–238 (*92*). Stationary method: with a long historical introduction and full references.

66*a*. GRIFFITHS, H. Phil. Trans. **184**. 361–504 (*93*). Determination by an electrical method.

An interesting method was used by

66*b*. CANTONI & GEROSA. Beibl. **7**. 242 (*83*). [Abstract from Rend. Accad. Lincei.] Rise of temperature of mercury in falling.

J. Calorimetry.

The principal methods used for measuring quantities of heat and the secondary units adopted are described in Regnault's memoirs (see Nos. 105, 106) and in :—

67. FAVRE & SILBERMANN. Ann. Chim. Phys. (3) **34**. 357–450 (*52*). Calorimeters for chemical reactions.

68. BUNSEN. Pogg. **141**. 1–31 (*70*); or Phil. Mag. (4) **41**. 161–182 (*71*) (translation). Ice-calorimeter.

69. HIRN. C. R. **70**. 592–604, 831–834 (*70*). Specific heat of water.

70. JAMIN & AMAURY. C. R. **70**. 661–664 (*70*). Specific heat of water.

ROWLAND, H. (*Loc. cit.* No. 56.) Specific heat of water.

71. VELTEN. Wied. **21**. 31–64 (*83*). Specific heat of water.

72. THOMSEN, J. 'Thermochemische Untersuchungen.' Leipzig, 1882–86.

73. BERTHELOT. Ann. Chim. Phys. (5) **23**. 160–176 (*81*). "Calorimetric bomb" for heats of combustion.

74. BERTHELOT & VIEILLE. Ann. Chim. Phys. (6) **6**. 546–556 (*85*). "Calorimetric bomb" for heats of combustion.

75. BERTHELOT & RECOURA. Ann. Chim. Phys. (6) **13**. 289–304 (*88*). "Calorimetric bomb" for heats of combustion.

76. Joly. Proc. R. S. **41**. 352–371 (*87*). Condensation calorimeter.

77. ——. Proc. R. S. **47**. 218–245 (*90*).

78. Chappuis. Ann. Chim. Phys. (6) **15**. 498–517 (*88*). New method for latent heat of evaporation.

79. Mathias. Ann. Chim. Phys. (6) **21**. 69–144 (*90*); or more briefly in J. de Phys. (2) **9**. 449–467 (*90*). New method for latent heat of evaporation.

And for Berthelot's methods in general, see his 'Essai de Mécanique Chimique,' Vol. i. Paris, 1879.

K. General Thermodynamic Theory.

80. Carnot, S. 'Reflexions on the Motive Power of Heat.' (Transl.) London, 1890: Macmillan. Contains the earliest attempt at the theory. The most complete presentation of it is in the papers of Clausius, collected under the title:—

81. Clausius, R. 'Mechanical Theory of Heat.' (Transl. from 2nd edit. by Browne.) London, 1879.

(The original edition is 'Abhandlungen über die Mechanische Wärmetheorie.' 2 vols. Braunschweig, 1864–67; the revised edition, 'Mechanische Wärmetheorie.' 2 vols. Braunschweig, 1876–79.)

Other classical papers are:—

82. Joule & Thomson, W. Phil. Trans. 1853–54–60–62. Thermal effects of fluids in motion.

Reprinted in Sir W. Thomson's papers, vol. i. pp. 333–455.

83. Thomson, W. Trans. R. S. E. vol. **20**. Internal energy of bodies.

Reprinted in Sir W. Thomson's papers, vol. i. pp. 222–232.

84. Thomson, J. Trans. R. S. E. **16**. 575–580 (*49*). Change of freezing-point by pressure. Theory.

Reprinted in Sir W. Thomson's papers, vol. i. pp. 156–164.

85. Thomson, W. Phil. Mag. (3) **37**. 123–127 (*49*). Change of freezing-point by pressure. Experimental verification.

Reprinted in Sir W. Thomson's papers, vol. i. pp. 165–169.

86. Kirchhoff, G. Pogg. **103**. 177–206 (*58*). Internal energy of bodies.

87. Cazin. Ann. Chim. Phys. (4) **14**. 374–410 (*68*). Experiments in support of the theory of condensation and expansion of gases.

88. v. d. Waals. 'On the Continuity of the Liquid and Gaseous States:' translated under the direction of the Physical Society. London, 1890. [Original Dutch edition, 1873.]

89. Hirn. Ann. Chim. Phys. (4) **10**. 32–92 (*67*).
90. ——. Ann. Chim. Phys. (4) **11**. 5–112 (*67*).
Memoir on thermodynamics. First part experimental, on specific heat and volume of water. Second part, theoretical deductions.

91. Lippmann. J. de Phys. (2) **3**. 53–57, 277–283 (*84*). Explanation of absolute temperature, after Thomson: and development of a general formula for measuring it.

Much information is given also in treatises, especially those of Verdet, Zeuner, Hirn, and Rühlmann, not obtainable elsewhere.

The most convenient presentation of the laws of thermodynamics for use in particular cases has occupied the attention of several writers. Various methods are given by:—

92. Thomson, W. Phil. Mag. (5) **7**. 348–352 (*79*). On thermodynamic motivity.
Reprinted in Sir W. Thomson's papers, vol. i. pp. 456–459.

93. Massieu, F. C. R. **69**. 858-862, 1057–1061 (*69*). Characteristic functions of thermodynamics. Or more fully in Mém. Sav. étrangers, vol. **22**. (*76*), 92 pp.

94. Gibbs, J. Willard. Trans. Connecticut Acad. **3**. 108-248, 343–524 (*75–76*). Equilibrium of heterogeneous substances.

95. von Helmholtz, H. Berl. Sitzber. 1882, 22–39. Thermodynamics of chemical processes.

96. Gouy. J. de Phys. (2) **8**. 501–518 (*89*). Available energy.

97. Duhem. Ann. Sci. de l'École Norm. (3) **8**. 231–266 (*91*). General equations of thermodynamics.

97*a*. Natanson, L. Ostw. **10**. 733–747 (*92*). On the thermodynamic potential systematically treated.

Among recent papers of interest may be mentioned:—

98. Neumann, C. Leipz. Ber. (Math.-Phys. Cl.) **43**. 75–156 (*91*). Error in the customary formulation of the second law of thermodynamics.

99. Natanson, L. Wied. **42**. 178-185 (*91*). Remarks on the expression of the two laws.

100. Wiedemann, E. Wied. **38**. 485–487 (*89*). Expression of the second law in harmony with luminescence phenomena.

101. Budde, E. Wied. **45**. 751–758 (*91*). More exact treatment of temperature, as integrating divisor.

102. Ritter, A. Wied. **37**. 44–68, 633–646 (*89*); **40**. 356–369 (*90*). Detailed calculation of the effects of adiabatic compression of air: novel.

103. Gouy. C. R. **115**. 720–722 (*92*). Effect of gravity on fluids at the critical point.

104. Ramsay & Young. Phil. Trans. **175**. 37–48, 461–478 (*84*). Experiments on the vapour-pressure of solids and liquids at the same temperature.

104 *a*. Laar, J. J. van. Ostw. **11**. 721–736 (*93*). Useful collection of relations between thermal quantities at the critical point.

L. Thermodynamics of Fluids at rest. Experimental data.

Regnault's work has long been the standard of reference: it will be well to collect here the titles of his principal memoirs.

105. Regnault. Mém. de Paris, **21**. (*47*).
1–13. Introduction.
15–120. Expansion of gases.
121–162. Absolute density of gases.
163–270. Thermometry; especially gas-thermometers.
271–328. Expansion of mercury.
329–428. Deviation from Boyle's law.
429–464. Compressibility of liquids.
465–633. Saturation-pressure of water-vapour.
635–728. Heat of vaporisation of water.
729–748. Specific heat of liquid water.

106. ——. Mém. de Paris, **26**. (*62*).
3–41. Historical introduction.
42–228. Specific heat of gas and vapours.
229–296. Data required for above—compressibility of gases, specific heat of liquids, &c.
297–333. Conclusions.
335–760. Saturation-pressure of vapours *in vacuo* and in air, and of mixed vapours.
761–915. Heat of vaporisation of liquids.

107. ——. Mém. de Paris, **37**. 579–959 (*68*). Expansion of gases. Heat absorbed in discharge from reservoir under pressure, through capillary tubes, &c.: heat evolved in compression. Deduction of the specific heat at constant volume.

A useful summary of more recent work is given by

108. Main, P. T. Rep. Brit. Ass. 1886, 100–140; 1888, 465–502.

M. Relations between Temperature, Pressure, and Volume: General.

109. Andrews. Phil. Trans. **159**. 575–590 (*69*).
110. ——. Phil. Trans. **166**. 421–449 (*76*).
On carbon dioxide: the work that led to the discovery of the critical point.

111. ——. Phil. Trans. **178**. 45–56 (*87*). Mixtures of gases.

112. Ramsay & Young. Phil. Trans. **177**. 71–122 (*86*).

113. ——— ———. Phil. Trans. **177**. 123–156 (*86*).

114. ——— ———. Phil. Trans. **178**. 57–94 (*87*).

115. ——— ———. J. C. S. **49**. 790–812 (*86*).

116. ——— ———. Phil. Trans. **178**. 313–335 (*87*).

117. ——— ———. J. C. S. **51**. 755–757 (*87*).

118. ——— ———. Phil. Trans. **180**. 137–158 (*89*).
Series of papers on evaporation and dissociation. Parts i., ii., iii., iv., v., vii., viii. Part vi. is theoretical. The most interesting sections are in Part i., on dissociable bodies, and Part iii., description of apparatus.

119. ——— ———. Phil. Trans. **183**. 107–130 (*92*). On water: same methods as above.

120. Amagat. Ann. Chim. Phys. (4) **29**. 246–285 (*73*). *Résumé* of work on compressibility of fluids.

121. ———. Ann. Chim. Phys. (5) **8**. 270–278 (*76*). Compressibility at low pressures.

122. ———. Ann. Chim. Phys. (5) **11**. 520–549 (*77*). Compressibility of liquids.

123. ———. Ann. Chim. Phys. (5) **19**. 345–385 (*80*). Compressibility of gases at high pressures.

124. ———. Ann. Chim. Phys. (5) **22**. 353–398 (*81*). Compressibility of gases at high pressures.

125. ———. Ann. Chim. Phys. (5) **28**. 456–464 (*83*). Compressibility of gases.

126. ———. Ann. Chim. Phys. (5) **28**. 464–480 (*83*). Compressibility of carbon dioxide.

127. ———. Ann. Chim. Phys. (5) **28**. 480–499 (*83*). Compressibility of mixtures of air and carbon dioxide.

128. ———. J. de Phys. (3) **1**. 288–297 (*92*). Improved method for volume of saturated liquids and vapours, with results for carbon dioxide.

129. ———. Ann. Chim. Phys. (6) **29**. 68–136, 505–574 (*93*). Collected results on fluids, particularly water. Methods, observations, and deductions.

130. Wroblewski. Wien. Ber. **97**. 1321–1379 (*89*). Study of hydrogen over large range of temperature and pressure. Deduction of critical point: discussion of corresponding temperatures. Posthumous and incomplete.

131. Barus, C. Phil. Mag. (5) **30**. 338–361 (*90*). Isometrics of ether, alcohol, &c.

131 *a*. Battelli, L. Beibl. **17**. 318–320 (*93*). Thermal properties of water: summary of results. [Abstract from Mem. Accad. Turin.]

N. Density at High Pressures.

132. Grassi. Ann. Chim. Phys. (3) **31.** 437–489 (*51*). Classical research on compressibility of liquids.

133. Tait. 'Challenger' Reports. Physics and Chemistry, vol. ii. part iv., 76 pp. (Abstracts in Proc. R. S. E. vols. 12 & 13.) On the compressibility of water.

O. Density at Low Pressures.

134. Siljeström. Pogg. **151.** 451–482, 573–603 (*74*). Boyle's law for pressures below one atmosphere.

135. Mendeléef. Ber. **7.** 1339–1344 (*74*). Boyle's law for pressures below one atmosphere. (Abstract, with ref. to Russian original.)

136. Dieterici. Wied. **38.** 1–26 (*89*). Density of water-vapour at 0° measured by Bunsen's calorimeter: novel.

P. Vapour-pressure and Density.

Much attention has been given lately to improving methods and to study of bodies with abnormal vapour-densities. We may mention :—

137. Meyer, V., & Goldschmidt. Ber. **15.** 1161–1164 (*82*).

138. Meyer, V., & Langer. 'Pyrochemische Untersuchungen.' Braunschweig, 1885. 73 pp.

139. Nilson & Petterson. J. für Prakt. Chem. **33.** 1–17 (*86*); or Ann. Chim. Phys. (6) **9.** 554–574 (*86*).

140. Biltz. Ber. **21.** 2013–2017, 2772–2776 (*88*). Density of sulphur-vapour.

141. Meyer, V. Ber. **21.** 2018–2019 (*88*). Density of sulphur-vapour.

142. Meyer, V., & Demuth. Ber. **23.** 311–316 (*90*). Method for vapour-densities at temperatures below the boiling-point.

143. Walker, J. Ostw. **2.** 602–605 (*88*). Method for slightly volatile bodies (adopted from Müller-Erzbach and Tamann).

144. Galitzine. Wied. **41.** 588–626, 770–800 (*90*). Experiments to test Dalton's law. With very full references to earlier work.

145. Hertz, H. Wied. **17.** 193–200 (*82*). Vapour-pressure of mercury: partly observed, partly calculated from thermodynamic reasoning.

146. Ramsay & Young. J. C. S. **49.** 37–49 (*86*). Vapour-pressure of mercury, deduced from observed relations for other fluids.

Q. Condensation of Gases and Density at Low Temperatures.

147. Faraday. Phil. Trans. **113**. 160–165 (*23*). Condensation of chlorine &c.

148. ——. Phil. Trans. **135**. 155–177 (*45*).

149. Natterer. Wien. Ber. **5**. 351–358 (*50*).

150. ——. Wien. Ber. **7**. 557–570 (*51*). Condensation of carbon dioxide &c.

151. ——. Wien. Ber. **12**. 199–209 (*54*).

152. ——. Pogg. **94**. 436–446 (*55*).

153. Pictet. C. R. **85**. 1214–1220 (*77*). Earliest condensation of oxygen.

154. Cailletet. C. R. **85**. 1213–1214, 1270–1271 (*77*). Earliest condensation of oxygen, carbon monoxide, and other "permanent" gases.

155. ——. C. R. **100**. 1033–1035 (*85*). Apparatus for condensation of oxygen.

156. Cailletet & Mathias. J. de Phys. (2) **5**. 549–564 (*86*). Density of liquefied gases and saturated vapours: heat of vaporisation. With historical introduction.

157. Wroblewski & Olszewski. Wied. **20**. 243–257 (*83*). Condensation of the "permanent" gases: method, and results: with historical introduction.

158. Olszewski. Wied. **31**. 58–74 (*87*). Density of liquid marsh-gas, oxygen, and nitrogen.

R. Expansion of Liquids and Gases.

Hirn. (*Loc. cit.* No. 89.) Expansion of water at high temperatures.

159. Thorpe & Rücker. J. C. S. **45**. 135–144 (*84*). Expansion of liquids: empirical relations.

160. Mendeléef. Ber. (Ref.) **17**. 129–131 (*84*). Expansion of liquids: empirical relations. (Abstract, with reference to Russian original.)

161. ——. Phil. Mag. (5) **33**. 99–131 (*92*). Review of work on expansion of water (translation in full).

162. Jolly. Pogg. Jubelb. 82–101 (*74*). Expansion of gases, and use of air-thermometer.

S. Critical Point and Corresponding Temperatures.

163. Heilborn, E. Ostw. **7**. 601–613 (*91*). Index to literature on critical point, and summary of numerical results.

164. Guldberg. Beibl. **7**. 350 (*83*). Discussion of experimental data on corresponding temperatures. (Abstract, with reference to Norwegian original.)

165. Vincent, C., & Chappuis. J. de Phys. (2) **5.** 58–64 (*86*). Determination of critical points: experimental detail.

166. Cailletet & Colardeau. Ann. Chim. Phys. (6) **25.** 519–534 (*92*). Determination of critical point of water in steel tubes: novel method. [More briefly in J. de Phys. **10.** 333–340 (*91*), or C. R. **112.** 1170–1176 (*91*).]

167. Young, S. J. C. S. **59.** 37–46 (*91*). New method for density of saturated liquids and vapours.

168. ——. Phil. Mag. (5) **33.** 153–185 (*92*). Comparison of law of corresponding temperatures, with experimental data.

169. Mathias. J. de Phys. (3) **1.** 53–73 (*92*). Comparison of law of corresponding temperatures, with experimental data.

169 *a.* ——. J. de Phys. (3) **2.** 1–12 (*93*). Discussion of the law of "rectilinear diameter." List of data on critical volumes.

T. Absolute Density of Gases.

170. Crafts. C. R. **106.** 1662–64 (*88*). Correction to Regnault's measurement.

171. Rayleigh, Lord. Proc. R. S. **43.** 356–363 (*87*). On the density of oxygen and hydrogen.

172. ——. Proc. R. S. **45.** 425–430 (*88*). On the density of oxygen and hydrogen.

173. Cooke. Proc. Amer. Acad. **24.** 202–233 (*89*). Chemical method for density of gases.

174. Joly. Phil. Mag. (5) **30.** 379–386 (*90*). Determination in a small vessel at high pressure.

175. Moissan & Gautier. C. R. **115.** 82–86 (*92*). Method for density of small quantities of gas.

175 *a.* Leduc, A. C. R. **115.** 311–313 (*92*). Summary of results on the density and atomic weight of oxygen and hydrogen.

175 *b.* Scott, A. Phil. Trans. **184.** 543–568 (*93*). Composition of water by volume. Description of apparatus and results.

U. Thermal Capacity of Fluids.

176. Wiedemann, E. Pogg. **157.** 1–42 (*76*); Wied. **2.** 195–217 (*77*). Specific heat at constant pressure of gas and vapours, and variation with temperature. Modification of Regnault's method.

177. Jamin. C. R. **71.** 336–341 (*70*). Direct measurement of specific heat at constant volume of gases.

178. Joly. Phil. Trans. **182.** 73–118 (*91*). Direct measurement by condensation calorimeter.

179. Röntgen. Pogg. **148.** 580–624 (*73*). Typical example of many determinations of the ratio of specific heats of gases, by Clément & Désorme's method. (Critical references to earlier work.)

179 *a*. Bartoli & Stracciati. Beibl. **17.** 638–640 (*93*). Experiments on the specific heat of water. [Abstract from the Nuovo Cimento.]

Hirn. (*Loc. cit.* No. 69.) Specific heat of water at high temperatures.

180. de Heen. Bull. Ac. Belg. (3) **15.** 522–528 (*88*). Variation of specific heat near the critical point.

181. Dieterici. Wied. **37.** 494–507 (*89*). Heat of vaporisation of water at 0° by Bunsen calorimeter.

In this connexion must be mentioned the work of Mallard and Le Châtelier, and of Berthelot, Sarrau, and Vieille, on explosives, which contains much valuable information on the specific heats of gases at high temperatures.

182. Mallard & Le Châtelier. C. R. **91.** 825–828 (*80*); **93.** 145–148, 962–965, 1014–1016, 1076–1079 (*81*); **95.** 599–601, 1352–1355 (*82*). Velocity of explosive waves: temperature of combustion and dissociation: pressure produced: and specific heat of gases. The results are collected in 'Recherches sur la combustion des mélanges gazeux explosives.' Paris, 1883.

For Berthelot's work, see his treatise on explosives: translated and condensed by Hake and Macnab: London, 1892 (with summaries of the work done since the publication of the French edition). The most important recent papers are :—

183. Berthelot. Ann. Chim. Phys. (6) **4.** 13–84 (*85*).

184. ——. Ann. Chim. Phys. (6) **6.** 556–574 (*85*).

185. ——. Ann. Chim. Phys. (6) **23.** 485–503 (*91*). On methyl nitrate—a typical set of experiments.

186. ——. J. de Phys. (2) **10.** 357–369 (*91*). Comparison of the pressure of explosives with Clausius' formula.

187. Michaelson, W. Wied. **37.** 1–23 (*89*). Experiments on the normal rate of propagation of explosions in gases.

187 *a*. Dixon, H. B. Phil. Trans. **184.** 97–188 (*93*). Rate of explosion in gases: bearing on chemical theory: review of Berthelot's work.

CAPILLARY PHENOMENA.

V. General Theory.

The classical works on the subject are—

LAPLACE. 'Mécanique Céleste,' vol. 10.

GAUSS. Commentat. Soc. Reg. Gött. vol. 7 (1832).

To which may be added :—

188. QUET. 'Rapport sur le Progrès de la Capillarité.' (Paris, 1867.) A valuable review of the earlier theories and experiments.

A recent treatise is that of

MATHIEU. 'Théorie de la Capillarité.' (Paris, 1883.) Devoted mainly to the application of the received theory to particular cases.

Memoirs of importance are :—

189. RAYLEIGH, Lord. Phil. Mag. (5) **16**. 309–315 (*83*). Arguments in favour of the existence of internal pressure in liquids.

190. DUHEM. Ann. Sci. de l'École Norm. (3) **2**. 207–254 (*85*). Examination of the received theory: thermodynamic methods shown to be necessary: results of ordinary theory confirmed.

191. RAYLEIGH, Lord. Phil. Mag. (5) **30**. 285–298, 456–475 (*90*); **33**. 209–220, 468–471 (*92*). Sketch of mathematical theory of surface-forces in liquids and gases.

192. WORTHINGTON. Phil. Mag. (5) **18**. 334–364 (*84*). Theory of internal equilibrium of liquids.

193. ——. Phil. Mag. (5) **16**. 339–344 (*83*). Explanation of the quantities occurring in Laplace's theory.

194. FUCHS, K. Wien. Ber. **98**. 740–751 (*89*). Correction to the value of the tension of a curved surface.

195. ——. Wien. Ber. **98**. 1362–1391 (*89*). Deduction of the principal capillary functions.

195 *a*. BAKKER, G. Ostw. **12**. 280–286, 670–678 (*93*). Theoretical discussion on the internal pressure of liquids.

195 *b*. V. D. WAALS, J. D. Beibl. **18**. 170–172, 525 (*93*). Thermodynamic theory of capillarity. [Abstract from Verh. Akad. Wetensk. Amsterdam.]

On closely allied subjects are :—

196. STEFAN, J. Wied. **29**. 655–664 (*86*). Relations between capillarity and evaporation and internal pressure of liquids.

197. RAYLEIGH, Lord. Proc. R. S. **47**. 281–287 (*90*). Surface-viscosity.

198. WORTHINGTON. Phil. Trans. **183.** 355–370 (*92*). Measurement of the elasticity for stretching, of alcohol.

W. Radius of Molecular Action.

199. QUINCKE. Pogg. **137.** 402–414 (*69*). With historical introduction.

200. REINOLD & RÜCKER. Phil. Trans. **177.** 627–684 (*86*). Measurement of soap-films.

200 *a.* —— ——. Phil. Trans. **184.** 505–530 (*93*). Further measurements: comparison of methods.

201. SOHNCKE, L. Wied. **40.** 345–355 (*90*). Limiting thickness of oil-film on water.

202. RÖNTGEN. Wied. **41.** 321–329 (*90*). Limiting thickness of oil-film on water.

203. DRUDE, P. Wied. **43.** 158–180 (*91*). Discussion of range of mol. action from soap-films.

204. REINOLD & RÜCKER. Wied. **44.** 778–783 (*91*). Remarks on Drude's paper.

X. Measurement of Capillary Constants.

Quincke's researches form the principal source of information on the value of the capillary constants; but some of his methods have been attacked as incorrect by Worthington and others. The papers are :—

205. QUINCKE. Pogg. **105.** 1–48 (*58*). Surface-tension of mercury (large drop method), with historical introduction.

206. ——. Pogg. **134.** 356–367 (*68*). Surface-tension of metals by weight of drops on melting.

207. ——. Pogg. **135.** 621–646 (*68*). Ditto: more extended paper, with theory.

208. ——. Pogg. **138.** 141–155 (*69*). Flat drops of liquefied metals.

209. ——. Pogg. **139.** 1–89 (*70*). Capillary phenomena at surface between two fluids: various methods of measurement.

210. ——. Pogg. **160.** 337–375, 560–588 (*77*). Capillary phenomena for solutions.

211. ——. Wied. **2.** 145–194 (*77*). Angle of contact and spreading of liquids on solids.

212. WORTHINGTON. Proc. R. S. **32.** 362–377 (*81*). More exact treatment of hanging-drops.

213. ——. Phil. Mag. (5) **20.** 51–66 (*85*). Criticism of Quincke's methods.

214. TRAUBE. J. f. Prakt. Chem. **34.** 292–311, 515–538 (*86*). On method of hanging-drops.

215. Quincke. Wied. **27**. 219-228 (*86*). Reply to Worthington and others.

216. Schiff. Ber. **15**. 2965-2975 (*82*). Surface-tension at boiling-point: method and examples.

217. de Heen. Bull. Acad. Belg. (3) **5**. 477–482, 492–504, 505–523 (*83*). Information on temperature-variation of the surface-tension.

218. Worthington. Phil. Mag. (5) **19**. 43–46 (*85*). On the use of a capillary multiplier.

219. Rayleigh, Lord. Phil. Mag. (5) **30**. 386–400 (*90*). Surface-tension of water (clean and contaminated) by the method of ripples.

219 *a*. Hall, T. P. Phil. Mag. **36**. 385–413 (*93*). New (weighing) methods for measuring surface-tension.

219 *b*. Ramsay & Shields. Phil. Trans. **184**. 647–674 (*93*). Temperature-variation of surface-tension—its bearing on the molecular complexity of liquids.

Y. Miscellaneous Phenomena.

220. Röntgen. Wied. **3**. 321–328 (*78*). Effect of surface-tension on the weight of solids dipping in liquids.

221. Schleiermacher. Wied. **8**. 52–83 (*79*). Effect of surface-tension on the weight of solids dipping in liquids. Observations on the thickening of liquids at solid surfaces.

222. Worthington. Phil. Mag. (5) **15**. 198–203 (*83*). On horizontal motion of floating bodies under capillary forces.

223. Quincke. Wied. **35**. 580–642 (*88*). Numerous observations on movements of fluids due to surface-tension: novel.

A great mass of observations, chiefly qualitative, on liquids removed from the action of gravity is contained in Plateau's researches:—

224. Plateau. Mém. de Belg. vols. 16, 23, 29, 31, 33, 36, 37 (1843 to 1869); mostly translated in Taylor's Scientific Memoirs, vols. 4 & 5, and Phil. Mag. 4th series, vols. 14, 22, 24, 33, 38, & 40.

Plateau's book, 'Statique des Liquides.' 2 vols. (Ghent, 1873.)

225. Rayleigh, Lord. Proc. R. S. **34**. 130–145 (*82*). Vibrations of liquid jets.

226. Matthiessen, L. Wied. **38**. 118–130 (*89*). Experimental verification of Thomson's theory of waves in liquids under the combined influence of gravity and surface-tension.

Z. Thermodynamics of Fluids at rest. Theory.

The form of the equation $f(p, v, \theta)=0$, expressing the relations between pressure, volume, and temperature, has been the subject of much attention, as, with a knowledge of the internal energy, it forms a complete statement of the properties of a fluid. (See papers of W. Thomson and Kirchhoff, under General Thermodynamic theory.)

227. Thomson, J. Proc. R. S. **20.** 1–8 (*71*); or Phil. Mag. (4) **43.** 227–234 (*72*). First gives an explanation of the discontinuity of the isothermals in passing from liquid to vapour.

v. d. Waals. (*Loc. cit.* No. 88.) Gives a theoretical investigation, and proposes an equation.

228. Clausius. Wied. **9.** 337–357 (*80*). Equation for carbon dioxide.

229. Sarrau. C. R. **94.** 639–642, 718–720, 845–847 (*82*).

230. ——. C. R. **101.** 941–944, 994–997, 1145–1148 (*85*).

231. ——. C. R. **110.** 880–884 (*90*).

Comparison of Clausius' formula with experiments, chiefly Amagat's, for several gases; and, in the later papers, a modification of the formula.

232. Amagat. Ann. Chim. Phys. (5) **28.** 500–507 (*83*). Discussion of equations $f(p, v, \theta)=0$.

233. Wroblewski. Wied. **29.** 428–451 (*86*). Representation of state of a fluid by isopyknics.

234. Ramsay & Young. Phil. Mag. (5) **20.** 515–530 (*85*). Some empirical relations between pressure, temperature, and latent heat.

235. —— ——. Phil. Mag. (5) **23.** 129–138 (*87*). On the nature of fluids: review of their experimental work.

236. —— ——. Phil. Mag. (5) **23.** 435–458 (*87*); (5) **24.** 196–212 (*87*). "Evaporation and dissociation," part vi. Discussion of form of isometric lines, and empirical relations observed.

237. Fitzgerald. Proc. R. S. **42.** 50–52, 216–224 (*87*). On some deductions from Ramsay and Young's experiments.

238. Jäger, G. Wien. Ber. **101.** 1675–1684 (*92*). Discussion of equations.

238 *a*. Brillouin, M. J. de Phys. (3) **2.** 113–118 (*93*). Comparison of equations of v. d. Waals, Clausius, and Sarrau, with the general equation of the third degree.

239. Cailletet & Colardeau. Ann. Chim. Phys. (6) **17**. 269–281 (*89*); or J. de Phys. (2) **8**. 389–396 (*89*). Maintain that both liquid and vapour exist above the critical point.

In this connexion should be mentioned certain experiments which, though dealing with fluids in motion, have as their object to determine the internal energy of gases.

Joule & Thomson, W. (*Loc. cit.* No. 82.) Especially paper on flow of gases through a porous plug.

Regnault. (*Loc. cit.* No. 107.) Heat absorbed in discharge of gases &c.

240. Natanson, E. Wied. **31**. 502–526 (*87*). Experiments on cooling of carbon dioxide by expansion, and comparison with v. d. Waals' theory.

241. Bouty. J. de Phys. (2) **8**. 20–28 (*89*). Discussion of internal energy of gases, according to v. d. Waals' and Clausius' equations, and comparison with Joule and Thomson's experiments.

242. Schiller, N. Wied. **40**. 149–156 (*90*). Discussion of internal energy of gases, according to v. d. Waals' and Clausius' equations, and comparison with Joule and Thomson's experiments.

AA. [Appendix.] Theory of Mixtures and Solutions.

The literature of this subject and the allied points, of dissociation and chemical combination, is very large: we can here only mention two or three papers of exceptional interest.

243. van't Hoff. Arch. Néerland. **20**. 239–302 (*86*). Comparison of dilute solutions to gases. [More briefly in Ostw. **1**. 481–508 (*87*).]

244. Boltzmann. Ostw. **6**. 474–480 (*90*). Discussion of van't Hoff's hypothesis from the point of view of the kinetic theory.

245. Lorentz, H. Ostw. **7**. 36–54 (*91*). Discussion of van't Hoff's hypothesis from the point of view of the kinetic theory.

246. Boltzmann. Ostw. **7**. 88–90 (*91*). Discussion of van't Hoff's hypothesis from the point of view of the kinetic theory.

247. van d. Waals. Arch. Néerland. **24**. 1–56 (*90*). On the thermodynamic equilibrium of mixtures.

247 *a*. Natanson, L. Ostw. **10**. 748–781 (*92*). Thermodynamic potential of solutions.

Thermodynamics of Solids.

The constitution of solids is more complicated than that of fluids, and has been much less studied; so that the experimental data existing fall into a few distinct groups, while of theory only a few isolated points have been developed, chiefly with regard to imperfections of elasticity in solids.

BB. Elasticity.

The most important data fall under this head; several moduli of elasticity have been measured, usually those of stretching and twisting; sometimes Young's modulus, by bending; sometimes the volume elasticity (see researches on compressibility of fluids). Innumerable measurements have been taken; it will only be necessary to mention as typical:—

248. Wertheim, G. Ann. Chim. Phys. (3) **12.** 385–454 (*44*).

249. ——. Ann. Chim. Phys. (3) **12.** 581–624 (*44*).

250. ——. Ann. Chim. Phys. (3) **15.** 114–120 (*45*).

251. ——. Ann. Chim. Phys. (3) **23.** 52–94 (*48*).

252. ——. Ann. Chim. Phys. (3) **50.** 195–322 (*57*).

253. ——. Ann. Chim. Phys. (3) **50.** 385–432 (*57*).

Much discussion has gone on as to the value of Poisson's ratio. Wertheim measured it; also:—

254. Kirchhoff. Pogg. **108.** 369–392 (*59*). For steel: static method.

254*a*. Everett. Phil. Trans. **156**. 185–191 (*66*); **157**. 137–153 (*67*); **158**. 363–369 (*68*). Flexural and torsional rigidity of metals and glass.

255. Schneebeli. Pogg. **140.** 598–621 (*70*). For steel, by longitudinal and torsional vibrations.

256. Cornu, A. C. R. **69.** 333–337 (*69*). By optical observations of bending.

257. Amagat. Ann. Chim. Phys. (6) **22.** 95–140 (*91*); or more briefly in J. de Phys. (2) **8.** 197–204, 359–368 (*89*). Compressibility and Poisson's ratio.

258. Threlfall. Phil. Mag. (5) **30.** 99–117 (*90*). Elastic constants of quartz threads.

259. Voigt, W. Wied. **31.** 474–501, 701–723 (*87*). Elastic constants of quartz and beryl (Baumgarten's method; one of several papers on different crystals).

The relation of elasticity to temperature has received little attention; we may refer to:—

260. Kohlrausch & Loomis. Pogg. **141.** 481–503 (*70*).

And the papers of H. Tomlinson, which, being of a somewhat miscellaneous character, may best be collected here:

261. Tomlinson, H. Phil. Trans. **174.** 1–172 (*83*). Elastic properties of metals.

262. Tomlinson, H. Proc. R. S. **38.** 488-500 (*85*). Relation of elasticity to thermal capacity &c.

263. ——. Proc. R. S. **43.** 88–108 (*87*). Comparison between static elasticity and velocity of sound in metals.

264. ——. Phil. Trans. **177.** 801–837 (*86*). Viscosity of solids; damping of vibrations, due to viscosity under various circumstances.

Thirteen pure metals have been investigated very systematically by

264 *a*. Voigt, W. Wied. **48.** 674–707 (*93*). Elasticity by flexural and torsional vibrations.

264 *b*. ——. Wied. **49.** 396–400 (*93*). Remarks on the above.

264 *c*. ——. Wied. **49.** 697–708, 709–718 (*93*). Thermal expansion, thermal pressure, and specific heat.

CC. Limits of Elasticity.

Viscosity, or internal friction of solids, leads naturally to the subject of "Elastische Nachwirkung," and the two must be taken together. The chief papers are (with Tomlinson's mentioned above):—

265. Weber, W. Pogg. **34.** 247–256 (*35*). Observations and theory of Elastische Nachwirkung.

266. ——. Pogg. **54.** 1–17 (*41*). Observations and theory of Elastische Nachwirkung.

267. Kohlrausch, F. Pogg. **119.** 337–368 (*63*). Observations and theory of Elastische Nachwirkung.

268. ——. Pogg. **128.** 1–20, 207–227, 399–419 (*66*). Observations and theory of Elastische Nachwirkung.

269. ——. Pogg. **155.** 579–587 (*75*). Observations and theory of Elastische Nachwirkung.

270. ——. Pogg. **158.** 337–375 (*76*). Observations and theory of Elastische Nachwirkung.

271. ——. Pogg. **160.** 225–238 (*77*). Observations and theory of Elastische Nachwirkung.

272. Wiedemann, G. Pogg. **103.** 563–577 (*58*). Observations on limits of elasticity, permanent and temporary deformation, and analogous magnetic phenomena.

273. ——. Pogg. **106.** 161–201 (*59*). Observations on limits of elasticity, permanent and temporary deformation, and analogous magnetic phenomena.

274. ——. Pogg. **107.** 376–379 (*59*). Observations on limits of elasticity, permanent and temporary deformation, and analogous magnetic phenomena.

275. ——. Pogg. **117.** 193–217 (*62*). Observations on limits of elasticity, permanent and temporary deformation, and analogous magnetic phenomena.

276. WIEDEMANN, G. Wied. **6.** 485–520 (*79*). Observations on limits of elasticity, permanent and temporary deformation, and analogous magnetic phenomena.

277. MAXWELL. "Constitution of bodies," Ency. Brit. 9th ed. 1876. Reprinted in Maxwell's collected papers, vol. ii. pp. 616–624.

278. MEYER, O. E. Pogg. **151.** 108–119 (*74*). Theory of El. Nachw.

279. ——. Pogg. **154.** 354–361 (*75*). Note on Streintz's work.

280. ——. Wied. **4.** 249–267 (*78*). Critical experiments and modified theory.

281. BOLTZMANN. Wien. Ber. **70.** 275–306 (*75*); or Pogg. Ergänzb. **7.** 624–654 (*76*). Theory of El. Nachw.

282. ——. Wien. Ber. **76.** 815–842 (*78*). Theory of El. Nachw.

283. ——. Wied. **5.** 430–432 (*78*). Note against O. E. Meyer.

284. NEESEN. Pogg. **153.** 498–525 (*74*). Experiments on torsion and extension of wires.

285. ——. Pogg. **157.** 579–596 (*76*). Experiments on torsion and extension of wires.

286. ——. Wied. **7.** 460–469 (*79*). Experiments on torsion and extension of wires.

287. STREINTZ. Wien. Ber. **69.** 337–378 (*74*); or Pogg. **153.** 387–411 (*74*). Experiments on damping of torsional vibrations.

288. SCHMIDT. Wied. **2.** 48–66 (*77*). Experiments on damping of torsional vibrations.

289. BRAUN, W., & KURZ, A. Carl's Rep. **15.** 561–577 (*79*). Experiments on damping of torsional vibrations.

290. ——, ——. Carl's Rep. **17.** 233–253 (*81*). Experiments on damping of torsional vibrations.

291. ——, ——. Carl's Rep. **18.** 665–672 (*82*). Experiments on damping of torsional vibrations.

292. WARBURG. Wied. **4.** 232–249 (*78*). Theory of El. Nachw.

293. ——. Wied. **10.** 13–24 (*80*). Experiments in support.

294. SCHRÖDER, T. Wied. **28.** 369–393 (*86*). Relation of El. Nachw. to temperature: experiments by Kohlrausch's method.

295. WIEDMANN, G. Wied. **29.** 214–249 (*86*). Elastic and thermal after-effects in glass.

296. REKKUH. Wied. **35.** 476–496 (*88*). El. Nachw. and temperature.

297. BARUS. Phil. Mag. (5) **26.** 183–217 (*88*); **27.** 155–177 (*89*). Experimental verification of Maxwell's theory of El. Nachw.

298. Barus & Strouhal. Sill. (3) **32.** 444–466 (*86*); **33.** 20–36 (*87*). Measurement of the viscosity of steel, with references to literature.

299. Brillouin. J. de Phys. (2) **7.** 327–347 (*88*); **8.** 169–179 (*89*). Thermodynamics of permanent strain:—Mathematical consequences of certain simple assumptions as to imperfectly elastic bodies.

On the important question of how elasticity of metals is affected by long continued strains, little information exists; experiments have been undertaken by

300. Bottomley. Phil. Mag. (5) **24.** 314–318 (*87*).

301. ——. Phil. Mag. (5) **28.** 94–98 (*89*),
and are still in progress.

Much information on breaking strains has been collected for engineering purposes, but it possesses little scientific interest at present. One or two other papers on allied points may be mentioned:—

302. Auerbach, F. Wied. **43.** 61–100 (*91*). Absolute measurement of hardness; description of apparatus and results, with historical introduction.

303. ——. Wied. **45.** 277–291 (*92*). General remarks on elastic properties of solids and on plasticity and brittleness.

304. Morin. Mém. Sav. étrang. (2) **4.** 1–128, 591–696 (*33*); **6.** 641–784 (*35*). Classical researches on friction.

305. Reynolds, O. Phil. Trans. **177.** 157–234 (*86*). Theory of lubrication and Mr. Beauchamp Tower's experiments.

DD. Thermal Expansion.

Two methods of measurement are commonly adopted, that of the comparator and Fizeau's optical method. Both methods have been studied very carefully at the Bureau International, and their publications contain the best account of the experimental details, and the most recent results.

306. Pernet. Trav. et Mém. du bureau int. des poids et mesures, vol. iv. 170 pp. (1885). On the comparator method.

307. Benoît. Trav. et Mém. du bureau int. des poids et mesures, vol. vi. 193 pp. (1888). On Fizeau's method.

See also the original papers by

308. Fizeau. C. R. **62.** 1101–1106, 1133–1148 (*66*).
309. ——. C. R. **66.** 1005–1014, 1072–1086 (*68*).

Experimental method and results, with application to different crystalline systems. The first memoir reprinted, Ann. Chim. Phys. (4) **8.** 325–361 (*66*); the second translated, Phil. Mag. (4) **36.** 31–38 (*68*).

310. Beckenkamp, J. Beibl. **6.** 80–86 (*82*). Thermal expansion of monosymmetric and asymmetric crystals: theory and measurements. (Abstract.)

EE. Thermal Capacity.

The ordinary methods of measurement will be found under Calorimetry. We need only mention here a few results of special interest.

311. Weber, H. F. Pogg. **154.** 367–423, 553–582 (*75*). Specific heat of carbon, boron, and silicon at various temperatures: Dulong and Petit's law.

312. Violle. J. de Phys. (1) **7.** 69–78 (*78*). Careful study of specific heat of platinum and allied metals up to melting-point.

313. ——. J. de Phys. (1) **9.** 81–85 (*80*). Careful study of specific heat of platinum and allied metals up to melting-point.

The anomalous behaviour of iron at high temperatures was the subject of much study a few years ago:—

314. Osmond. C. R. **103.** 743–746, 1135–1137 (*86*). Observations on the cooling of steel.

315. Pionchon. Ann. Chim. Phys. (6) **11.** 33–110 (*87*); or, more briefly, J. de Phys. (2) **6.** 269–286 (*87*). Calorimetric study of iron and other metals, over a large range of temperature. Description of method, and results.

316. Newall. Phil. Mag. (5) **24.** 435–439 (*87*). Observations on recalescence of steel.

317. ——. Phil. Mag. (5) **25.** 510–512 (*88*). Observations on recalescence of steel.

318. Tomlinson, H. Phil. Mag. (5) **23.** 245–252 (*87*). General remarks on the elastic properties of iron.

319. ——. Phil Mag. (5) **25.** 103–116 (*88*). Recalescence.

320. Barus. 'Nature,' **41.** 369–371 (*90*). Note on the stability of iron and steel.

321. Osmond. Mém. de l'Artill. de la Marine, vol. xv. (1887), 131 pp. *Résumé* of subject, with references to literature.

For calculations on internal energy of solids, and their specific heat at constant volume, see Wüllner: Experimental-Physik, vol. iii. p. 61 (4th edit.). Calculation first given by W. Thomson, Proc. Roy. Soc. viii. (1857); also Trans. Roy. Soc. Edinb. (1851).

FF. Phenomena of Fusion.

322. Kopp. Lieb. **93.** 129–232 (*55*). Change of volume on melting.

323. Barus. Phil. Mag. (5) **29.** 337–355 (*90*). Experimental comparison of viscosity of solids and liquids.

324. ——. Sill. (3) **42.** 125–147 (*91*). Continuity of solid and liquid states.

325. Wiedemann, E. Wied. **20.** 228–242 (*83*). Change of volume of metals on melting.

326. Person, C. Ann. Chim. Phys. (3) **21.** 295–335 (*47*); (3) **24.** 129–162, 265–276 (*48*); (3) **27.** 250–272 (*49*). Numerous observations on heat of fusion.

See also "Calorimetry" for heat of fusion of ice.

327. Raoult. Ann. Chim. Phys. (6) **8.** 289–317 (*86*). Lowering of freezing-point of solutions.

328. ——. Ann. Chim. Phys. (6) **8.** 317–339 (*86*). Method for determining molecular weights.

These two papers may be taken as representative of the extensive literature now existing on "Raoult's method" for molecular weights, a subject belonging rather to Chemistry than Physics.

Thermodynamics of Moving Fluids.

Note.—In the sections following on Diffusion and Viscosity it is intended to refer only to experimental work, with such theoretical considerations as do not involve any assumptions as to molecules. It is impossible to separate such papers completely from those on molecular theory, so additional information will be found later, where experiments on Diffusion and Viscosity are treated as data of the kinetic theory of gases.

GG. Diffusion of Gases.

329. Graham. Phil. Trans. **136.** 573–631 (*46*). Transpiration and effusion of gases.

330. ——. Phil. Trans. **139.** 349–391 (*49*). Transpiration and effusion of gases.

331. ——. Phil. Trans. **153.** 385–405 (*63*); or Phil. Mag. (4) **26.** 409–434 (*63*). Diffusion of gases.

332. Loschmidt. Wien. Ber. **61.** 367–380 (*70*); **62.** 468–478 (*70*). Determination of coefficients.

333. v. Obermayer. Wien. Ber. **81.** 1102–1127 (*80*). Temperature variation of coefficient.

334. ——. Wien. Ber. **85.** 147–168, 748–761 (*82*). Coefficients for various gases.

335. ——. Wien. Ber. **87.** 188–263 (*83*). Coefficients for various gases.

336. ——. Wien. Ber. **96.** 546–577 (*87*). Possible variability of coefficient.

337. Winkelmann. Wied. **22.** 1–31, 152–160 (*84*). Measurements of diffusion and comparison with theory.

338. ——. Wied. **33.** 445–453 (*88*). Observations on rate of evaporation.

339. ——. Wied. **36.** 93–114 (*89*). Experiments on rate of evaporation and diffusion of vapours in air, hydrogen, and carbon dioxide.

340. Stefan. Wien. Ber. **98.** 1418–1442 (*89*); or Wied. **41.** 725–747 (*90*). Evaporation and solution treated as phenomena of diffusion: theory and experiments.

341. de Heen. Bull. Ac. Belg. (3) **21.** 11–24, 214–219, 798–810 (*91*). Experiments on rate of evaporation under various circumstances.

HH. Diffusion of Liquids.

342. Graham. Phil. Trans. **140.** 1–46, 805–836 (*50*); **141.** 483–494 (*51*). Experiments on diffusion of various liquids.

343. ——. Phil. Trans. **144.** 177–228 (*54*). Osmotic force.

344. Stefan. Wien. Ber. **78.** 957–975 (*78*). Experiments on diffusion of liquids. Description of method.

345. ——. Wien. Ber. **79.** 161–214 (*79*). Reduction of Graham's results.

(See also Stefan, under Diffusion of Gases.)

345*a*. Wiener, O. Wied. **49.** 105–149 (*93*). On curved rays and their application to measure diffusion of liquids.

II. Viscosity of Gases.

346. Maxwell. Phil. Trans. **156.** 249–268 (*66*). Determination by oscillating disc method.

(Reprinted in Maxwell's papers, vol. ii. p. 1.)

347. Puluj. Wien. Ber. **69.** 287–320 (*75*); **70.** 243–270 (*75*); **73.** 589–628 (*76*). Variation with temperature.

348. Kundt & Warburg. Pogg. **155**. 337–366, 525–550 (*75*); **159**. 399–415 (*76*). Measurement of viscosity, and slipping at glass surfaces.

349. v. Obermayer. Wien. Ber. **71**. 281–308 (*75*); **73**. 433–474 (*76*). Variation with temperature.

350. Klemenčič. Wien. Ber. **84**. 146–167 (*81*). Damping in air at various pressures.

351. Tomlinson. Phil. Trans. **177**. 767–799 (*86*). Oscillating disc method. With note by Stokes.

352. Barus. Wied. **36**. 358–398 (*89*). Viscosity of various gases up to 1000°, by capillary-tube method. Full references to literature.

The resistance of air at high velocities has been studied for practical purposes, and some results of interest obtained. See:—

353. Bashforth. Treatise on the Motion of Projectiles. London, 1873.

354. Langley. Smithsonian Contributions to Knowledge, vol. xxvii. (1891), 115 pp. (no. 801). Experiments on motion of inclined planes through the air. (Flying machines.)

355. Rayleigh, Lord. 'Nature,' **45**. 108–109 (*91*). Note on Langley's experiments.

JJ. Viscosity of Liquids.

356. Poiseuille. Mém. Sav. étrang. **9**. 433–544 (*46*); or Abstract in Ann. Chim. Phys. (3) **7**. 50–74 (*43*). Method of capillary tubes.

Many measurements have since been made by the same method, but without any noticeable difference. As an example of the method of damping we may take

357. König, W. Wied. **32**. 193–222 (*87*).

358. Stefan. Wien. Ber. **46**. 8–31, 495–520 (*62*). Gives a general mathematical treatment of the motion of viscous liquids, with particular application to Poiseuille's method.

The possible rigidity of liquids has been studied by

359. Schwedoff, Th. J. de Phys. **8**. 341–359 (*89*). Experiments on rigidity of twisted liquids, and Maxwell's theory of it. Connexion between viscosity and rigidity.

360. ——. J. de Phys. **9**. 34–46 (*90*). Experiments on rigidity of twisted liquids, and Maxwell's theory of it. Connexion between viscosity and rigidity.

KK. Outflow of Liquids.

Researches on this subject have been undertaken chiefly by engineers for practical purposes. See especially Weisbach in the 'Civilingenieur,' 1859 and on. Also

361. Reynolds, O. Proc. R. S. **35.** 84–99 (*83*). On the conditions for formation of eddies in flowing liquids.

LL. Outflow of Gases.

Experiments on this subject, though undertaken also for engineering purposes, have led to discussions of far more scientific interest than in the case of liquids. The most important data are those given by Hirn.

362. Hirn. Mém. de Belg. **43.** (1881), 91 pp. Experimental researches. Published separately by Gauthier-Villars, of Paris.

363. ——. Mém. de Belg. **46.** (1886), 203 pp. Experimental researches. Published separately by Gauthier-Villars, of Paris.

364. ——. Ann. Chim. Phys. (6) **7.** 289–349 (*86*). On the existence of a limiting velocity.

His experiments are uncontested, but Hirn draws conclusions from them at variance with the kinetic theory of gases; and a discussion accordingly arose in which various authors defended the theory against Hirn, explaining his experiments differently. See :—

365. Clausius. Bull. Ac. Belg. (3) **11.** 173–193 (*86*).

366. Hugoniot. Ann. Chim. Phys. (6) **9.** 375–405 (*86*).

Also articles by Hirn, Hugoniot, Parenty, and Haton de la Goupillière in the 'Comptes Rendus,' vols. 102, 103, and 104; especially

367. Haton de la Goupillière. C. R. **103.** 661–665, 709–712 (*86*). Exact theory of the variable outflow of a gas.

MM. Atmospheric Movements.

368. Fournier, E. F. C. R. **100.** 47–50 (*85*). Calculation of the pressure and velocity in cyclones.

369. Mascart. J. de Phys. (2) **8.** 557–572 (*89*). Abstract of experiments by M. Weyher on artificial reproduction of cyclones.

370. Oberbeck. Berl. Sitzber. 1888, 383–396, 1129–1138. On atmospheric movements.

371. Helmholtz, H. von. Berl. Sitzber. 1888, 647–663. On atmospheric movements.

372. ——. Berl. Sitzber. 1889, 761–780. On atmospheric movements.

373. ——. Berl. Sitzber. 1890, 853–872. On atmospheric movements.

Or Wied. **41.** 641–662 (*90*), reprint of the last of the above three papers.

374. v. Bezold. Berl. Sitzber. 1888, 485–522, 1189–1206.

375. ——. Berl. Sitzber. 1890, 355–390, 1295–1317.

376. ——. Berl. Sitzber. 1892, 279–309.

377. Rayleigh, Lord. Phil. Mag. (5) **29.** 173–180 (*90*). Vibrations of an atmosphere.

Wave-motions: especially Sound.

Two great works on Sound must first be mentioned, which give information on most of the subjects mentioned below, and much of it original. These are Helmholtz's 'Sensations of Tone' (fourth German edition, 1877; second English edition, edited, with valuable appendices, by Ellis: London, 1885); and Lord Rayleigh's 'Theory of Sound,' 2 vols. (London, 1877–78: Macmillan).

NN. Measurement of Frequency.

On this comparatively simple subject we need only refer to two or three of the more recent papers:—

378. Michelson. Sill. (3) **25.** 61–64 (*83*). Example of the electrochronographic method.

379. Leman. Zs. f. Instrumentenk. **10.** 77–87, 170–183, 197–202 (*90*). Determination of pitch of tuning-forks, undertaken for the Berlin 'Reichsanstalt.' Literature and criticism of methods and introduction only.

380. Herrmann, L. Pflüger's Archiv, **45.** 582–592 (*89*); **47.** 44–53, 347–391 (*90*); **53.** 1–51 (*93*). Full details of method of photographing vibrations. Analysis of vowel sounds.

380 *a*. Krigar-Menzel & Raps. Wied. **44.** 623–641 (*91*); **50.** 444–455 (*93*). Photographing motion of plucked strings. Analysis of curves.

380 *b*. Raps, A. Wied. **50.** 193–220 (*93*). Photographing interference-bands formed by sound-waves in air. Composition of vowel sounds.

OO. Velocity.

381. Regnault. Mém. de Paris, **37**. 3–575. Velocity of propagation of waves in gaseous media; direct measurement in tubes and in free air. References to earlier experiments.

382. Wertheim. Ann. Chim. Phys. (3) **23**. 434–474 (*48*). Velocity in liquids by wave-length of pipes.

383. ——. Ann. Chim. Phys. (3) **31**. 385–432, 432–436 (*51*). Velocity in air.

384. Kundt. Pogg. **127**. 497–523 (*66*). Velocity in gases and solids; determination of wave-length by dust figures.

385. ——. Pogg. **135**. 337–372, 527–561 (*68*). Velocity in pipes: with historical introduction.

386. Stefan. Wien. Ber. **57**. 697–708 (*68*). Velocity in solids.

387. Warburg. Pogg. **136**. 285–295 (*69*). Velocity in soft bodies (Stefan's method).

PP. Measurement of Intensity.

388. Rayleigh, Lord. Phil. Mag. (5) **14**. 186–187 (*82*). Action of sound on light plates.

389. Allard. C. R. **95**. 1062–1064 (*82*). Experiments on intensity at various distances from the source of sound.

390. Dvořák, V. Zs. f. Instrumentenk. **3**. 127–135 (*83*). Apparatus for production of rotation by sound-waves, and measurement of intensity.

391. Wien, M. Wied. **36**. 834–857 (*89*). Measurement by means of variation of pressure in a resonator. Proof of inverse square law. References to literature.

QQ. Quality of Tone.

For experiments and discussion of this subject, see especially Helmholtz's 'Sensations of Tone,' and

392. König, R. Pogg. **146**. 161–199 (*72*). Method of manometric flames.

393. ——. Pogg. **157**. 177–237 (*76*). Observations on consonances &c.

394. ——. J. de Phys. (2) **1**. 525–542 (*82*); or Wied. **14**. 369–393 (*81*). Effect of phase on quality. Experiments with the wave siren.

395. ——. Wied. **39**. 395–402, 403–411 (*90*). Observations on interference of sounds.

396. Voigt, W. Wied. **40**. 652–660 (*90*). Attempt to reconcile the theories of Helmholtz and König.

396 *a*. Herrmann, L. Pflüger's Archiv, **49**. 499–518 (*91*). Theory of combination-tones.

RR. Miscellaneous.

A few other papers may be mentioned:—

397. Stefan. Wien. Ber. **53**. 521–537 (*66*). Calculation of the effect of viscosity of air on propagation of sound.

398. Rayleigh, Lord. Phil. Mag. (5) **16**. 181–186 (*83*). Calculation of the absorbent effect of porous bodies.

399. Strouhal. Wied. **5**. 216–251 (*78*). Theory of organ-pipes, with experiments on production of tones, and on "Reibungstöne."

400. Herroun & Yeo. Proc. R. S. **50**. 318–322 (*92*). Audibility of single sound-waves.

Conduction of Heat.

The theory of conduction (or diffusion) assuming the conductivity not to vary with the temperature has been worked out by Fourier, whose work is a monument of applied mathematics, useful in several branches of Physics besides the present. The most accessible edition is:—

Fourier. 'Analytical Theory of Heat.' (Translated by A. Freeman.) Cambridge, 1878.

SS. Conductivity of Solids and Liquids.

The following are some of the numerous determinations that have been made:—

401. Wiedemann & Franz. Pogg. **89**. 497–531 (*53*). Relative conductivity of solids.

402. Forbes. Trans. R. S. E. **23**. 133–146 (*62*); **24**. 73–110 (*65*). Temperature-variation of conductivity in solids.

403. Ångström. Pogg. **114**. 512–530 (*61*). Absolute conductivity of metals.

404. ——. Pogg. **118**. 423–431 (*63*). Absolute conductivity of metals.

405. ——. Pogg. **123**. 628–640 (*64*). Absolute conductivity of metals.
Or Phil. Mag. (4) **25**. 130–142 (*63*); **26**. 161–167 (*63*). Translation in full of the first two memoirs.

406. Weber, H. F. Wied. **10**. 103–129 (*80*). Conductivity of solids.

407. Lorberg. Wied. **14**. 291–308, 426–450 (*81*). Analysis and reduction of H. F. Weber's work.

408. Lorenz, L. Wied. **13**. 422–447 (*81*). Comparison of conductivity of metals for heat and electricity.

409. Jannettaz. Beibl. **7**. 277–280 (*83*). On conductivity of crystals. (Abstract, with references to various papers of Jannettaz.)

410. Bottomley. Phil. Trans. **172**. 537–545 (*81*). Conductivity of water: original method.

411. Berget. C. R. **105**. 224–227 (*87*).

412. ——. C. R. **106**. 1152–1155 (*88*).

413. ——. C. R. **107**. 171–172, 227–229 (*88*).

Conductivity of mercury by the "method of the plate": temperature-variation: and conductivity of other liquids and metals.

413 *a*. ——. C. R. **114**. 1350–1352 (*93*). New method for comparing conductivity of solids: ingenious and simple.

414. Chree. Proc. R. S. **43**. 30–48 (*87*). Conductivity of liquids.

415. Graetz. Wied. **18**. 79–94 (*83*). Conductivity of liquids: novel method: cooling of a stream of liquid.

416. ——. Wied. **25**. 337-357 (*85*). Conductivity of liquids: novel method: cooling of a stream of liquid.

Some of the above papers refer to the loss of heat from the surface of bodies (external conductivity); and we may mention one or two other papers on the subject, though not properly belonging to Physics of Matter.

417. Stefan. Wien. Ber. **79**. 391–428 (*79*). Discussion of early experiments on radiation and enunciation of the law of the fourth power of the temperature.

418. Graetz. Wied. **11**. 913–930 (*80*). Law of radiation and emissivity of glass.

419. Ayrton & Kilgour. Phil. Trans. **183**. 371–406 (*92*). Emissivity of wires.

TT. Conductivity of Gases.

The experimental data are given here; but see also 'Kinetic Theory of Gases' for a discussion of the results.

420. Stefan. Wien. Ber. **65**. 45–72 (*72*).

421. Kundt & Warburg. Pogg. **156**. 177–211 (*75*).

422. Graetz. Wied. **14**. 232–260 (*81*).

Winkelmann has made numerous determinations, of which we need only mention the last, which, according to the author, is the best.

423. Winkelmann, A. Wied. **44**. 177–205, 429–456 (*91*).

The above are by the method of cooling. A stationary method, using an electrically-heated wire in a glass tube, was used by

424. SCHLEIERMACHER. Wied. **34**. 623–646 (*88*). Conductivity of gases.

425. ——. Wied. **36**. 346–357 (*89*). Conductivity of mercury-vapour, with discussion of its bearing on the theories of Boltzmann and O. E. Meyer.

MOLECULAR THEORY.

This has been worked out systematically only for gases. The ordinary Kinetic theory assumes either hard spherical atoms, or spherical or point atoms repelling one another according to a law depending on the distance, and combinations of such atoms. This theory has been built up by a few distinguished writers, each of whom has dealt with all the more important phenomena to be explained:—pressure, viscosity, diffusion, conduction, &c. We cannot, therefore, conveniently divide the subject. In addition to the memoirs mentioned below, the books of O. E. Meyer, 'Theorie der Gase' (Breslau, 1877), pp. 338, and Rühlmann, 'Handbuch d. Mech. Wärmetheorie,' vol. ii. pp. 1–253 (Braunschweig, 1885), contain much original information.

UU. **Kinetic Theory of Gases.**

426. WATERSTON, J. J. Phil. Trans. **183**. 1–80 (*92*). On the physics of media composed of free and perfectly elastic media in a state of motion. This paper was written in 1845, but not published, and consequently exercised no influence on the work of Clausius, Maxwell, &c., much of whose work it anticipated.

427. CLAUSIUS. Pogg. **100**. 353–380 (*57*).

428. ——. Pogg. **105**. 239–258 (*58*).

429. ——. Pogg. **115**. 1–56 (*62*).

These form Nos. 14, 15, and 16 in Part ii. of the Collected Papers (1st edit., 1867). They calculate the principal quantities involved in the theory—pressure, free path, &c., but on the assumption of equal speed in all the molecules, but directions of motion uniformly distributed.

430. MAXWELL. Phil. Mag. (4) **19**. 19–32 (*60*); **20**. 21–37 (*60*). Maxwell's Collected Papers, vol. i. pp. 377–409. Hard spherical theory: introduction of the "probability" distribution of speed in the molecules. Viscosity: diffusion: outline of general theory. (Some of his deductions, however, are not strict.)

431. ——. Phil. Trans. **157**. 49–88 (*67*); or Phil. Mag. (4) **35**.

129–145, 185–217 (*68*). Collected Papers, ii. 26–78. Theory based on the law of the inverse fifth power. Viscosity, diffusion, conductivity. See note on it by

432. Boltzmann. Wien. Ber. **66**. 213–219 (*72*).
433. Maxwell. Collected Papers, ii. 713–741; or more briefly in Phil. Mag. (5) **14**. 299–312 (*82*). On Boltzmann's theorem of distribution of energy in a system of material points.
434. Stefan. Wien. Ber. **47**. 81–97, 326–345 (*63*). General remarks on the theory of gases: pressure, conductivity.
435. ——. Wien. Ber. **63**. 63–124 (*71*). General theory of diffusion of gases: application to particular cases, and calculation of coefficients.
436. ——. Wien. Ber. **65**. 323–363 (*72*). Theory of diffusion and viscosity.
437. Meyer, O. E. Pogg. **125**. 177–209, 401–420, 564–599 (*65*).
438. ——. Pogg. **127**. 253–281, 353–382 (*66*).
439. ——. Pogg. **143**. 14–26 (*71*).
440. ——. Pogg. **148**. 1–44, 203–236, 526–555 (*73*).
    Theory of viscosity of gases: theory of methods for determining it: and results. This work is included in Meyer's 'Kinetische theorie der Gase.'

The results of Meyer's papers are contained in his book, referred to above, which also gives an account of the literature, generally, up to date of publication.

Boltzmann has worked out the theory of gases systematically, paying special attention to the conditions of equilibrium of the molecules and the law of distribution of velocities. See:—

441. Boltzmann. Wien. Ber. **56**. 682–690 (*67*). Number of atoms in the molecule and internal energy of gases.
442. ——. (General theory.) Wien. Ber. **58**. 517–560 (*68*). Equilibrium of kinetic energy between material moving points.
443. ——. Wien. Ber. **58**. 1035–1044 (*68*). Mathematical note to the preceding.
444. ——. Wien. Ber. **63**. 379–418 (*71*). Equilibrium of polyatomic molecules.
445. ——. Wien. Ber. **63**. 679–711 (*71*). General law of thermal equilibrium.
446. ——. Wien. Ber. **66**. 275-370 (*72*). Further studies on thermal equilibrium.
447. ——. Wien. Ber. **72**. 427–457 (*76*). Thermal equilibrium and external forces.

448. Boltzmann. Wien. Ber. **74**. 553–560 (*77*). Note on distribution of energy in the molecule.

449. ——. Wien. Ber. **84**. 136–145 (*80*). Note on theory of equilibrium.

450. ——. Wien. Ber. **95**. 153–164 (*87*). Correction to theory of equilibrium.

451. ——. (Viscosity.) Wien. Ber. **81**. 117–158 (*80*). Theory of viscosity. Evaluation of constant: references to literature.

452. ——. Wien. Ber. **84**. 40–135 (*82*). Theory of viscosity. Evaluation of constant: references to literature.

453. ——. Wien. Ber. **84**. 1230–1263 (*82*). Theory of viscosity. Evaluation of constant: references to literature.

454. ——. (Diffusion.) Wien. Ber. **86**. 63–99 (*82*). Diffusion: theory: review of experiments: references.

455. ——. Wien. Ber. **88**. 835–860 (*83*). Diffusion: theory: review of experiments: references.

456. ——. (Conductivity.) Wien. Ber. **72**. 458–470 (*76*); or Pogg. **157**. 457–469 (*76*). Conductivity of gases: distinction between transfer of translational and intramolecular energy.

457. ——. (Miscellaneous.) Wien. Ber. **75**. 62–100 (*77*). On meaning of the second law and other points.

458. ——. Wien. Ber. **78**. 7–46 (*79*). Second law and equilibrium of a heavy gas.

459. ——. Wien. Ber. **78**. 733–763 (*79*). Second law and diffusion.

460. ——. Wien. Ber. **89**. 714–722 (*84*); or Wied. **24**. 37–44 (*85*). Possibility of a kinetic theory based on attractive forces only.

461. Tait. Trans. R. S. E. **33**. 65–95 (*86*).

462. ——. Trans. R. S. E. **33**. 251–277 (*86*).

463. ——. Trans. R. S. E. **35**. 1029–1041 (*90*).

464. ——. Trans. R. S. E. **36**. 257–272 (*91*).

On the foundations of the kinetic theory. Chiefly on the Maxwell-Boltzmann hypothesis of distribution.

There have been interesting discussions on points in the kinetic theory, lately, in 'Nature' and the 'Philosophical Magazine.' See:—

465. Tait. Phil. Mag. (5) **21**. 343–349 (*86*). Abstract of papers in the Trans. R. S. E. on the Maxwell-Boltzmann hypothesis.

466. Burbury. Phil. Mag. (5) **21**. 481–483 (*86*). Note on the above.

467. Tait. Phil. Mag. (5) **23**. 141–145 (*87*). Further points.

468. Boltzmann. Phil. Mag. (5) **23**. 305–333 (*87*). On the assumption involved in Avogadro's hypothesis [translated from Wien. Ber. **94**. 613–643 (*86*)].

469. Tait. Phil. Mag. (5) **23**. 433–434 (*87*). Note on the above.

470. Boltzmann. Phil. Mag. (5) **25**. 81–103 (*88*). Questions in the kinetic theory [translated from Wien. Ber. **96**. 891–918 (*87*)].

471. Tait. Phil. Mag. (5) **25**. 172–179 (*88*). Reply to Boltzmann.

472. Culverwell. Phil. Mag. (5) **30**. 95–99 (*90*). On the attainment of the "special state" in a gas.

473. Burbury. Phil. Mag. (5) **30**. 298–317 (*90*). Law of distribution &c.

474. Rayleigh, Lord. Phil. Mag. (5) **33**. 356–359 (*92*). Remarks on Maxwell's investigation of Boltzmann's theorem.

475. Kelvin, Lord. Phil. Mag. (5) **33**. 466–468 (*92*). Test case of the Maxwell-Boltzmann hypothesis.

476. Burbury. Phil. Trans. **183**. 407–422 (*92*). Investigation of law of distribution in certain cases of colliding bodies.

477. Rayleigh, Lord. Nature, **44**. 499 (*91*). On v. d. Waals' virial equation.

478. ——. Nature, **44**. 597 (*91*). On v. d. Waals' virial equation.

479. ——. Nature, **45**. 80–82 (*91*). On v. d. Waals' virial equation.

480. Korteweg. Nature, **45**. 152–154 (*91*). On v. d. Waals' virial equation.

481. Tait. Nature, **44**. 546–547 (*91*). On v. d. Waals' virial equation.

482. ——. Nature, **44**. 627–628 (*91*). On v. d. Waals' virial equation.

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