have shown that a temperature not much above 0° C. prevails at the bottom of the ocean even between the tropics. A very gradual circulation is thus produced on a very large scale.

The rapid currents which are observed on some parts of the surface of the ocean are probably due to wind. Among these may be mentioned the Gulf Stream. This current of warm water forms a kind of immense river in the midst of the sea, differing in the temperature, saltness, and colour of its waters from the medium in which it flows. Its origin is in the Gulf of Mexico, whence it issues through the straits between the Bahamas and Florida, turns to the north-west, and splits into two branches, one of which goes to warm the coasts of Ireland and Norway, the other gradually turns southwards, traverses the Atlantic from north to south, and finally loses itself in the regions of the equator.

"The Gulf Stream is a river in the ocean; in the severest droughts it never fails, and in the mightiest floods it never overflows; its banks and its bottom are of cold water, while its current is of warm; it takes its rise in the Gulf of Mexico, and empties into Arctic seas. There is on earth no other such majestic flow of waters. Its current is more rapid than the Mississippi or the Amazon, and its volume more than a thousand times greater. Its waters, as far out from the Gulf as the Carolina coasts, are of indigo blue. They are so distinctly marked that their line of junction with the common sea-water may be traced by the eye. Often one-half of the vessel may be perceived floating in Gulf Stream water, while the other half is in common water of the sea, so sharp is the line."—(Maury, *Physical Geography of the Sea.*)

It would appear that an accumulation of water is produced in the Gulf of Mexico by the trade-wind which blows steadily towards it over the South Atlantic, and that the elevation of level thus occasioned is the principal cause of the Gulf Stream.

EXAMPLES.

[The Centigrade Scale is employed, except where otherwise stated.]

Scales of Temperature.

1. The difference between the temperatures of two bodies is 30° F. Express this difference in degrees Cent. and in degrees Réau.

2. The difference between the temperatures of two bodies is 12° C. Express this difference in degrees Réau. and in degrees Fahr.

3. The difference between the temperatures of two bodies is 25° R. Express this difference in the Cent. and Fahr. scales.

4. Express the temperature 70° F. in the Cent. and Réau. scales.

5. Express the temperature 60° C. in the Réau. and Fahr. scales.

6. Express the temperature 30° R. in the Cent. and Fahr. scales.

7. Air expands by ·00366 of its volume at the freezing-point of water for each degree Cent. By how much does it expand for each degree Fahr.?

8. The temperature of the earth increases by about one degree Fahr. for every 50 feet of descent. How many feet of descent will give an increase of 1° Cent., and how many centimetres of descent will give an increase of 1° Cent., the foot being 30·48 cm.?

9. The mean annual range of temperature at a certain place is 100° F. What is this in degrees Cent.?

10. Lead melts at 326° C., and in melting absorbs as much heat as would raise 5·37 times its mass of water 1° C. What numbers will take the place of 326 and 5·37 when the Fahrenheit scale is employed?

11. Show that the temperature −40° C. and the temperature −40° F. are identical.

12. What temperature is expressed by the same number in the Fahr. and Réau. scales?

Expansion.

The following coefficients of expansion can be used:—

Linear.		Cubical.	
Steel,	·0000116	Glass,	·000024
Copper,	·0000172	Mercury,	·000179
Brass,	·0000188	Alcohol,	·001050
Glass,	·0000080	Ether,	·001520

13. The correct length of a steel chain for land measuring is 66 ft. Express, as a decimal of an inch, the difference between the actual lengths of such a chain at 0° and 20°.

14. One brass yard-measure is correct at 0° and another at 20°. Find, as a decimal of an inch, the difference of their lengths at the same temperature.

15. A lump of copper has a volume 258 cc. at 0°. Find its volume at 100°.

16. A glass vessel has a capacity of 1000 cc. at 0°. What is its capacity at 10°?

17. A weight-thermometer contains 462 gm. of a certain liquid at 0° and only 454 gm. at 20°. Find the mean relative expansion per degree between these limits.

18. A weight-thermometer contains 325 gm. of a liquid at zero, and 5 gm. run out when the temperature is raised to 12°. Find the mean coefficient of apparent expansion.

19. If the coefficient of relative expansion of mercury in glass be $\frac{1}{6500}$, what mass of mercury will overflow from a weight-thermometer which contains 650 gm. of mercury at 0° when the temperature is raised to 100°?

20. The capacity of the bulb of a thermometer together with as much of the stem as is below zero is ·235 cc. at 0°, and the section of the tube is $\frac{1}{2000}$ sq. cm. Compute the length of a degree (1), if the fluid be mercury; (2), if it be ether.

21. The bulb, together with as much of the stem as is below the zero-point, contains 3·28 gm. of mercury at zero, and the length of a degree is ·1 cm. Compute the section of the tube, the density of mercury being about 13·6.

22. What will be the volume at 300° of a quantity of gas which occupies 1000 cc. at 0°, the pressure being the same?

23. What will be the volume at 400° of a quantity of gas which occupies 1000 cc. at 100°, the pressure being the same?

24. What will be the pressure at 30° of a quantity of gas which at 0° has a pressure of a million dynes per sq. cm., the gas being confined in a close vessel whose expansion may be neglected?

25. A thousand cc. of gas at 1·0136 million dynes per sq. cm. are allowed to expand till the pressure becomes a million dynes per sq. cm., and the temperature is at the same time raised from its initial value 0° to 100°. Find the final volume.

26. A gas initially at volume 4500 cc., temperature 100°, and a pressure represented by 75 cm. of mercury, has its pressure increased by 1 cm. of mercury and its temperature raised to 200°. Find its final volume.

27. At what temperature will the volume of a gas at a pressure of a million dynes per sq. cm. be 1000 cc., if its volume at temperature 0° and pressure 1·02 million dynes per sq. cm. be 1200 cc.?

28. What temperature on the Fahrenheit scale is the absolute zero of the air-thermometer?

29. Find the coefficient of expansion of air per degree Fahrenheit, when 0° F. is the starting-point.

30. Express the freezing-point and boiling-point of water as absolute temperatures Fahrenheit.

31. What is the interior volume at 0° C. of a glass bulb which at 25° C. is exactly filled by 53 grammes of mercury?

For Densities of Gases see p. 50.

32. At what temperature does a litre of dry air at 760 mm. weigh 1 gramme?

33. At what temperature will the density of oxygen at the pressure 0·20 m. be the same as that of hydrogen at 0° C., at the pressure 1·60 m.?

[The tabulated densities are proportional to the values of $\frac{DT}{P}$ for the different gases.]

34. What must be the pressure of air at 15°, that its density may be the same as that of hydrogen at 0° and 760 mm.?

35. A mercurial barometer with brass scale reads at one time 770 mm. with a temperature 85°, and at another time 760 mm. with a temperature 5°. Find the ratio of the former pressure to the latter.

36. The normal density of air being ·000154 of that of brass, what change is produced in the force required to sustain a kilogramme of brass in air, when the pressure and temperature change from 713 mm. and −19° to 781 mm. and +36°?

37. A cylindrical tube of glass is divided into 300 equal parts. It is loaded with mercury, and sinks to the 50th division from the top in water at 10°. To what division will it sink in water at 50°, the volumes of a given mass of water at these temperatures being as 1·000268 to 1·01205?

38. A closed globe, whose external volume at 0° is 10 litres, is immersed in air at 15° and at a pressure of 0·77 m. Required (1) the loss of weight which it experiences from the action of the air; (2) the change which this loss would undergo if the pressure became 0·768 m. and the temperature 17°.

39. A brass tube contains mercury, with a piece of platinum immersed in it; and the level of the liquid is marked by a scratch on the inside of the tube. On applying heat, it is found that the liquid still stands at this mark. Deduce the ratio of the weight of the platinum to that of the mercury, assuming the density of platinum to be 21·5, and its linear expansion ·00001 per degree.

40. A glass tube, closed at one end and drawn out at the other, is filled with dry air, and raised to a temperature x at atmospheric pressure. It is then hermetically sealed. When it has been cooled to the temperature 100° C., it is inverted over mercury, and its pointed end is broken off beneath the surface of the liquid. The mercury rises to the height of 19 centimetres in the tube, the external pressure remaining at 76 cm. as at the commencement of the experiment. The tube is re-inverted, and weighed with the mercury which it contains. The weight of this mercury is found to be 200 grammes; when completely full it contains 300 grammes of mercury. Deduce the temperature x.

41. A glass tube, whose interior is a right circular cylinder, 2 millimetres in diameter at 0° C., contains a column of mercury, whose length at this temperature is 2 decim. What will be the length of this column of mercury when the temperature is 80° C.?

42. Some dry air is inclosed in a horizontal thermometric tube, by means of an index of mercury. At 0° C. and 0·760 m. the air occupies 720 divisions of the tube, the tube being divided into parts of equal capacity. At an unknown temperature and pressure the same air occupies 960 divisions. The tube being immersed in melting ice, and the latter pressure being still maintained, the air occupies 750 divisions. Required the temperature and pressure.

43. A Graham's compensating pendulum is formed of an iron rod, whose length at 0° C. is l, carrying a cylindrical vessel of glass, which at the same temperature has an internal radius r, and height h. Find the depth x of mercury at 0° C. which is necessary for compensation, supposing that the compensation consists in keeping the centre of gravity of the mercury at a constant distance from the axis of suspension.

Thermal Capacity.

The following values of specific heat can be used:—

Iron,	·1098	Mercury,	·033
Copper,	·0949	Alcohol,	·548
Platinum,	·0335	Ether,	·529
Sand,	·215	Air, at constant pressure,	·2375
Ice,	·504		

44. 17 parts by mass of water at 5° are mixed with 23 parts at 12°. Find the resulting temperature.

45. 200 gm. of iron at 300° are immersed in 1000 gm. of water at 0°. Find the resulting temperature.

46. Find the specific heat of a substance 80 gm. of which at 100°, when immersed in 200 gm. of water at 10° give a resulting temperature of 20°.

47. 16 parts by mass of sand at 75°, and 20 of iron at 45° are thrown into 50 of water at 4°. Find the temperature of the mixture.

48. 300 gm. of copper at 100° are immersed in 700 gm. of alcohol at 0°. Find the resulting temperature.

49. If the length, breadth, and height of a room are respectively 6, 5, and 3 metres, how many gramme-degrees of heat will be required to raise the temperature of the air which fills the room by 20°, the pressure of the air being constant, and its average density ·00128 gm. per cubic centimetre?

50. Find the thermal capacities of mercury, alcohol, and ether per unit volume, their densities being respectively 13·6, ·791, and ·716.

Latent Heat.

The following values of latent heat can be used:—

In Melting.		In Evaporation at Atmospheric Pressure.	
Water,	80	Steam,	536
Lead,	5·4		

51. Find the result of mixing 5 gm. of snow at 0° with 23 gm. of water at 20°.

52. Find the result of mixing 6 parts (by mass) of snow at 0° with 7 of water at 50°.

53. Find the result of mixing 3 parts by mass of snow at −10° with 8 of water at 40°.

54. Find the result of mixing equal masses of snow at −10° and water at 60°.

55. Find the temperature obtained by introducing 10 gm. of steam at 100° into 1000 gm. of water at 0°.

56. Lead melts at 326°. Its specific heat is ·0314 in the solid, and ·0402 in the liquid state. Find what mass of water at 0° will be raised one-tenth of a degree by dropping into it 100 gm. of melted lead at 350°.

57. What mass of mercury at 0° will be raised 1° by dropping into it 150 gm. of lead at 400°?

58. A litre of alcohol, measured at 0° C., is contained in a brass vessel weighing 100 grammes, and after being raised to 58° C., is immersed in a kilogramme

of water at 10° C., contained in a brass vessel weighing 200 grammes. The temperature of the water is thereby raised to 27°. What is the specific heat of alcohol? The specific gravity of alcohol is 0·8; the specific heat of brass is 0·1.

59. A copper vessel, weighing 1 kilogramme, contains 2 kilogr. of water. A thermometer composed of 100 grammes of glass and 200 gr. of mercury, is completely immersed in this water. All these bodies are at the same temperature, 0° C. If 100 grammes of steam at 100° C. are passed into the vessel, and condensed in it, what will be the temperature of the whole apparatus when equilibrium has been attained, supposing that there is no loss of heat externally. The specific heat of mercury is 0·033; of copper, 0·095; of glass, 0·177.

Various.

60. A truly conical vessel contains a certain quantity of mercury at 0° C. To what temperature must the vessel and its contents be raised that the depth of the liquid may be increased by $\frac{1}{150}$ of itself?

61. There is a bent tube, terminating at one end in a large bulb, and simply closed at the other. A column of mercury stands at the same height in the two branches, and thus separates two quantities of air at the same pressure. The air in the bulb is saturated with moisture; that in the opposite branch is perfectly dry. The length of the column of dry air is known, and also its initial pressure, the temperature of the whole being 0° C. Calculate the displacement of the mercurial column when the temperature of the apparatus is raised to 100° C. The bulb is supposed to have enough water in it to keep the air constantly saturated; and is also supposed to be so large that the volume of the moist air is not sensibly affected by the displacement of the mercurial column.

Conduction.

(Units the centimetre, gramme, and second.)

62. How many gramme-degrees of heat will be conducted in an hour through each sq. cm. of an iron plate ·02 cm. thick, its two sides being kept at the respective temperatures 225° and 275°, and the mean conductivity of the iron between these temperatures being ·12?

63. Through what thickness of copper would the same amount of heat flow as through the ·02 cm. of iron in the preceding question, with the same temperatures of its two faces, the mean conductivity of the copper between these temperatures being unity?

64. How much heat will be conducted in an hour through each sq. cm. of a plate of ice 2 cm. thick, one side of the ice being at 0° and the other at −3°, and its conductivity being ·00223; and what volume of water at 0° would be converted into ice at 0° by the loss of this quantity of heat?

65. How much heat will escape in an hour from the walls of a building, if their area be 80 sq. metres, their thickness 20 cm., their material sandstone of conductivity ·01, and the difference of temperature between outside and inside 15°? What quantity of charcoal burned per hour would generate heat equal to this loss? [see p. 220.]

Hygrometry.

66. A cubic metre of air at 20° is found to contain 11·56 grammes of aqueous vapour. What is the relative humidity of this air, the maximum pressure of vapour at 20° being 17·39 mm.?

67. Calculate the weight of 15 litres of air saturated with aqueous vapour at 20° and 750 mm.

Thermodynamics.

For the value of Joule's equivalent see § 205.

For heats of combustion see § 230.

68. The labour of a horse is employed for 3 hours in raising the temperature of a million grammes of water by friction. What elevation of temperature will be produced, supposing the horse to work at the rate of 6×10^9 ergs per second?

69. From what height (in cm.) must mercury fall at a place where g is 980, in order to raise its own temperature 1° by the destruction of the velocity acquired, supposing no other body to receive any of the heat thus generated?

70. With what velocity (in cm. per sec.) must a leaden bullet strike a target that its temperature may be raised 100° by the collision, supposing all the energy of the motion which is destroyed to be spent in heating the bullet?

71. What is the greatest proportion of the heat received by an engine at 200° that can be converted into mechanical effect, if the heat which is given out from the engine is given out at the temperature 10°?

72. If a perfect engine gives out heat at 0°, at what temperature must it take in heat that half the heat received may be converted?

73. What mass of carbon burned per hour would produce the same quantity of heat as the work of one horse for the same time, a horse-power being taken as 75×10^8 ergs per second.

74. A specimen of good coal contains 88 per cent. of carbon and $4\frac{1}{2}$ per cent. of hydrogen not already combined with oxygen. How many gramme-degrees of heat are generated by the combustion of 1 gm. of this coal; and with what velocity must a gramme of matter move that the energy of its motion may be equal to the energy developed by the combustion of the said gramme of coal?

75. Find the form of the isothermals for steam in contact with water.

76. In the cycle ABCD of § 215 or § 250, show that the volumes and pressures at A and B are proportional to those at D and C.

Adiabatic Compression and Extension.

77. Find the rise of temperature produced in water at 10° C. by an atmosphere of additional pressure, an atmosphere being taken as a million dynes per sq. cm., and the coefficient of expansion at this temperature being ·000092.

78. Find the ratio of the adiabatic to the isothermal resistance of water at 10° to compression, the value of the latter being $2{\cdot}1 \times 10^{10}$ dynes per sq. cm.

79. Find the fall of temperature produced in a wrought iron bar by applying a pull of a million dynes per sq. cm. of section, the coefficient of expansion being ·0000122.

80. Find the ratio of the adiabatic to the isothermal resistance of the bar to extension, the value of the latter being $1{\cdot}96 \times 10^{12}$ dynes per sq. cm.

ANSWERS TO EXAMPLES.

Ex. 1. $16°\frac{2}{3}$ C., $13°\frac{1}{3}$ R. Ex. 2. $9°\frac{3}{5}$ C., $21°\frac{3}{5}$ F. Ex. 3. $31°\frac{1}{4}$ C., $56°\frac{1}{4}$ F. Ex. 4. $21°\frac{1}{9}$ C., $16°\frac{8}{9}$ R. Ex. 5. 48° R., 140° F. Ex. 6. $37°\frac{1}{2}$ C., $99°\frac{1}{2}$ F. Ex. 7. ·00203. Ex. 8. 90 ft., 2743 cm. Ex. 9. $55°\frac{5}{9}$ C. Ex. 10. 619°, 9·666. Ex. 12. −25·6.

Ex. 13. ·184 in. Ex. 14. ·0135 in. Ex. 15. 259·33 cc. Ex. 16. 1000·24 cc. Ex. 17. ·000881. Ex. 18. ·001302. Ex. 19. $\frac{650}{66} = 9{\cdot}85$ gm. Ex. 20. (1) ·073 cm., (2) ·703 cm. Ex. 21. ·000374 sq. cm.

Ex. 22. 2098 cc. Ex. 23. 1804 cc. Ex. 24. 1·1098 million. Ex. 25. 1385 cc. Ex. 26. 5631 cc. Ex. 27. −50°.

Ex. 28. −459°. Ex. 29. $\frac{1}{459}$. Ex. 30. 491°, 671°. Ex. 31. 3·913 cc. Ex. 32. 80° C. Ex. 33. 272°. Ex. 34. 55·5 mm. Ex. 35. 759·7 : 759·4. Ex. 36. ·155 − ·140 = ·015 grammes of increase in the apparent weight.

Ex. 37. 47·3. Ex. 38. Loss of 12·42 gm., diminished by ·12 gm. Ex. 39. The ratio of the platinum to the mercury is 4·6 to 1 by volume, and 7·3 to 1 by weight. Ex. 40. 1219°, neglecting expansions of glass and mercury.

Ex. 41. 2·026 decim. Ex. 42. 76°·5, ·7296 m. Ex. 43. $\cdot15l + \cdot1h$.

Ex. 44. 9°·02. Ex. 45. 6°·44. Ex. 46. $\frac{5}{16} = \cdot3125$. Ex. 47. 10°. Ex. 48. 6°·91. Ex. 49. 547200. Ex. 50. ·449, ·433, ·379.

Ex. 51. Water at $2°\frac{1}{7}$. Ex. 52. $1\frac{5}{8}$ part snow, $11\frac{3}{8}$ water, all at zero. Ex. 53. Water at 5·9. Ex. 54. ·313 snow, 1·687 water, all at zero. Ex. 55. Water at 6°·3. Ex. 56. 16600 gm. nearly. Ex. 57. 84400 gm. nearly.

Ex. 58. ·687. Ex. 59. 28·7. Ex. 60. 88°. Ex. 61. The displacement x is given by the equation $2x = 753{\cdot}7 - \frac{373}{273}\frac{px}{l-x}$, p and l being the given pressure and length.

Ex. 62. 1080000. Ex. 63. $\frac{1}{6}$ cm. $= \cdot166\dot{6}$ cm. Ex. 64. 12·04 gm.-deg., ·15 cc. Ex. 65. 21600000 gm.-deg., 2673 gm.

Ex. 66. 67 per cent. Ex. 67. 17·68 gm.

Ex. 68. 1°·56. Ex. 69. 1401 cm. Ex. 70. 16240 cm. per sec. Ex. 71. $\frac{200}{473} =$ ·4 nearly. Ex. 72. 273°. Ex. 73. 80·32 gm. Ex. 74. 8661 gm.-deg., 849000 cm. per sec. nearly.

Ex. 75. Straight lines, because pressure is constant.

Ex. 76. If m denote the ratio of the temperature in AB to that in CD, the ratio of the two pressures either at A and D or at B and C is m raised to the power $s/(s-s')$, and the ratio of the volumes is $1/m$ to the power $s'/(s-s')$; see §§ 220, 250.

Ex. 77. 0°·000626. Ex. 78. 1·0012. Ex. 79. 0°·00009. Ex. 80. 1·002.