CHAPTER V.

HEAT.

I.—GENERAL PROPERTIES OF HEAT.

Definition of Heat.

176. HEAT is a physical agent capable of exciting in us the sensation which we call *warmth*. Absence of heat constitutes *cold*.

Theories of Heat.

177. Two principal theories have been advanced to explain the phenomena of heat.

According to the first theory, heat is a fluid, destitute of weight, and capable of flowing from one body to another. The particles of this fluid mutually repel each other, and are attracted by the particles of other bodies. This is called the *emission theory*.

According to the second theory, heat consists of a vibratory motion of the particles of bodies, which motion is transmitted from one body to another through an elastic fluid, called *ether*, in the same manner that sound is transmitted through air. The warmest bodies are those in which these vibrations are most rapid and most extensive. This is the *undulatory theory*.

According to the emission theory, a body cools by losing

(**176.**) What is Heat? Cold? (**177.**) What two theories of heat have been advanced? Explain the emission theory. The undulatory theory.

a portion of the fluid; according to the undulatory theory, they simply lose a part of their motion.

In the progress of science, the undulatory theory seems to be growing into favor, but for the purposes of explanation, the emission theory is preferable.

General Effects of Heat.

178. Heat, accumulating in bodies, penetrates into their substance, and uniting with their ultimate molecules, gives rise to repellent forces which counteract those of cohesion. Hence, the most noticeable phenomenon of heat is, that it causes bodies *to expand*. If applied in sufficient quantity, the particles of solids are so far repelled, as to move freely amongst each other, becoming *liquid;* or if still greater quantities of heat are applied, the body passes into a *state of vapor*. When heat is abstracted from a vapor, it returns to a liquid state, and if still more heat be abstracted, it becomes solid, and if the process be continued, the solid goes on contracting under the influence of the molecular forces.

Hence we say, that heat *dilates* bodies, and cold contracts them. Heat also converts solids into liquids, liquids into vapors, and acting upon gases and vapors, causes them to expand.

Expansion of Bodies by Heat.

179. All bodies are expanded by heat, but in very different degrees. The most dilatable bodies are gases, then vapors, then liquids, and finally solids. In fluids we regard only increase of volume, but in solids we distinguish two kinds of expansion, *linear expansion*, that is, expansion in length, and *expansion of volume*.

(**178.**) Describe the general effects of heat on solids. On liquids. What effect has cold on vapors? On liquids? (**179.**) What bodies are most dilatable? The least dilatable? What is linear expansion? Expansion of volume?

Fig. 126 represents the method of showing and measuring the linear expansion of the metals. A rod of metal, *A*, passes through two metallic supports, being made fast at one extremity by a clamp-screw, *B*, and being free to expand at the other extremity. The free end abuts against the short end, *C*, of a lever, the long end, *D*, of which plays in front of a graduated arc.

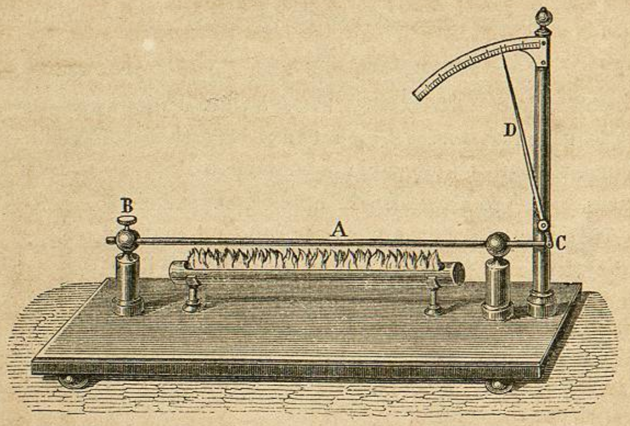


Fig. 126.

When the rod is heated, by placing fire beneath it, as shown in the figure, the rod *A* expands, and the expansion is shown by the

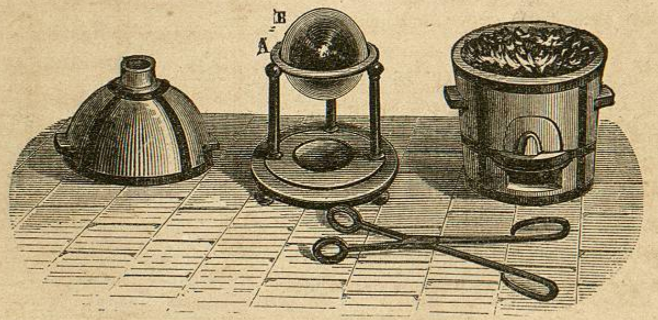


Fig. 127.

How is the linear expansion of metals shown?

motion of the index, *D*. When the rod, *A*, is of steel, copper, silver, &c., the amount of expansion varies, as is shown by the different amounts of displacement of the index. Brass, for example, expands more, for the same amount of heat, than iron or steel.

Fig. 127 shows the method of demonstrating that bodies undergo an expansion in volume when heated. A ring, *A*, is constructed so that a ball, *B*, passes freely through it when cold. If the ball be heated in a furnace, it will no longer pass through the ring, but if allowed to cool, it again falls through the ring. The method of making the experiment is fully shown in the figure.

Liquids and gases being more expansible than solids, their expansion is more easily shown by experiment. For liquids, we take a hollow glass sphere, terminating in a narrow tube, open at the top, and fill the globe and a portion of the stem with some fluid, like mercury, as shown in Fig. 128. If heat be applied to the globe, the liquid will rise in the stem from *a* towards *b*, indicating an increase of volume; and if sufficient heat be applied, the liquid will fill the stem, and will ultimately be converted into vapor. If the liquid is allowed to cool, it again returns to its original volume.

An analogous experiment shows the expansion of gases and vapors. A bulb of glass is provided with a long and fine tube of the same material, which is bent twice upon itself, as shown in Fig. 129. An index of mercury is introduced into the stem in the following manner. The bulb is heated, and a portion of the air which it contains is driven

Fig. 128.

Fig. 129.

How is expansion in volume shown? How is the expansion of liquids shown? Of gases?

out, when a drop of mercury is poured into the funnel, *a*. If the instrument is allowed to cool, the air in the bulb contracts, and the pressure of the atmosphere drives the drop of mercury along the tube to some position, *m*.

The instrument having been prepared in this manner, if the bulb is held in the hand for a few minutes, the air becomes heated and expands, the expansion being indicated by the index moving to some new position, as *n*. If allowed to cool, the index returns to *m*.

From what precedes, we infer that heat expands all bodies, and that cold contracts them. There are apparent exceptions to this law, but they are only apparent. Thus, bodies capable of absorbing water, like paper, wood, clay, and the like, contract on being heated. This contraction is only apparent; it arises from the water which they contain being vaporized and driven off, which produces an apparent diminution of volume; after they are thoroughly dried, they follow the general law.

The phenomenon just explained is used for bending absorbent bodies. To effect this they are heated on one side only, which drives out the water from that side, and causes them to bend in that direction. It is this principle that causes wooden articles to warp, and therefore demands that articles of furniture, and wooden parts of structure, be coated with oils, paints, or varnishes, to prevent the absorption of water.

The principle of expansion and contraction is often utilized in the arts.

A familiar example, is the process of setting the tire of a wagon-wheel. The tire is made a little smaller than the outer periphery of the wooden part of the wheel. It is then heated, and placed around the wheel; on cooling, it contracts powerfully, and draws the felloes firmly together. The same principle has been applied

---

What is the general conclusion with respect to the action of heat and cold? Explain the apparent exceptions to the law. *Explain the process of warping Are the principles of contraction and expansion utilized? Explain the operation of setting a tire. Of drawing walls together.*

in bringing the walls of a building back to their original position after they had begun to separate from each other.

Sensible and Latent Heat. — Temperature.

180. When the heat received by a body is attended with an increase of warmth, the heat is said to be *sensible*.

In certain cases a body may receive a large amount of heat without any increase of warmth. Such heat is said to be *latent*.

The *temperature* of a body is the degree of heat which it manifests: if the body grows warm, its temperature is said to rise; if it grows cool, its temperature is said to fall.

II. — THERMOMETERS.

The Thermometer.

181. A Thermometer is an instrument for measuring temperatures.

The thermometer depends upon the principle that bodies expand when heated, and contract when cooled. Thermometers have been constructed of a great variety of materials. For common purposes, the mercurial thermometer is preferred, on account of the uniformity with which both mercury and glass expand when heated.

The mercurial thermometer consists of a bulb of glass, at the upper extremity of which is a narrow tube of uniform bore, hermetically sealed at its upper end. The bulb and a part of the tube are filled with mercury, and the whole is attached to a frame on which is a scale for measuring the rise and fall of the mercury in the tube.

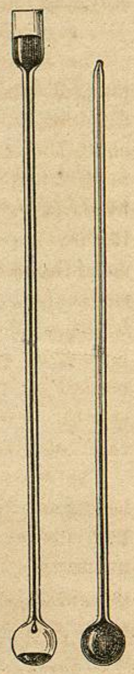
(**180.**) What is sensible heat? Latent heat? Temperature? (**181.**) What is a Thermometer? On what principle does it depend? What is the best thermometer for common use? Describe a mercurial thermometer.

Method of making a Thermometer.

182. A capillary tube of glass is provided, of uniform bore, upon one end of which a bulb is blown, and upon the other a funnel, as shown in Fig. 130.

The funnel is nearly filled with mercury, which is at first prevented from penetrating into the bulb by the resistance of the air and the smallness of the tube. The bulb is therefore heated, when the air within expands, and a portion escapes in bubbles through the mercury. On cooling, the pressure of the external atmosphere forces a quantity of mercury through the tube into the bulb. By repeating this operation a few times, the bulb and a portion of the tube are filled with mercury.

The whole is then heated till the mercury boils, thus filling the tube, when the funnel is melted off and the tube hermetically sealed by means of a jet of flame urged by a blow-pipe. On cooling, the mercury descends to some point of the tube, as shown in Fig. 131, leaving a vacuum at the upper point. It only remains to graduate it, and attach a suitable scale.



Figs. 130. 131.

Method of Graduation.

183. Two points of the stem are first determined, the *freezing* and the *boiling point*. These are determined on the principle that the temperatures at which distilled water freezes and boils, are always the same, that is, when these changes of state take place under equal atmospheric pressures.

The instrument is first plunged into a bath of melting ice, as shown in Fig. 132, and is allowed to remain until it takes the

(**182.**) *Describe the process of filling a thermometer with mercury. How is the tube sealed?* (**183.**) *On what principle are the freezing and boiling points determined?*

temperature of the mixture, say twenty or thirty minutes. A slight scratch is then made on the stem at the upper surface of the mercury, and this constitutes the *freezing point.*

The instrument is next plunged into a bath of distilled water, in a state of ebullition, care being taken to surround it with steam by means of an apparatus like that shown in Fig. 133. After the mercury ceases to rise in the tube, which will be in a few minutes, the level of its upper surface is marked on the stem, by a scratch, as before, and this constitutes the *boiling point.*

The space between the boiling and freezing points is then divided into a certain number of equal parts, and the graduation is continued above and below as far as may be desired. These divisions may be scratched upon the glass with a diamond, or, as is usually done, they may be made on a strip of metal, which is attached to the frame. The divisions are numbered according to the kind of scale adopted.

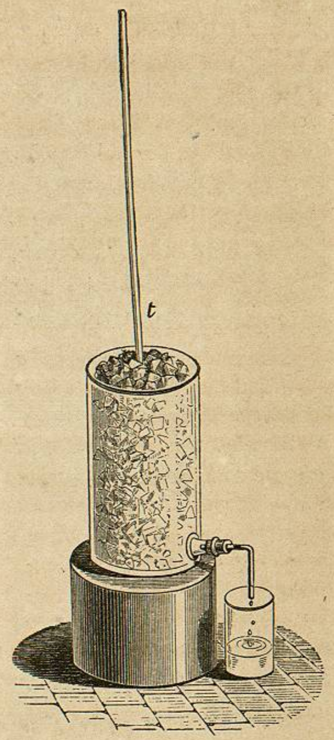


Fig. 132.

Thermometer Scales.

184. Three principal scales are used: the *Centigrade scale*, in which the space between the freezing and boiling

How is the freezing point determined? The boiling point? How is the intermediate space divided? (**184.**) What are the three principal scales used?

points is divided into 100 equal parts, called *degrees;* *Reaumur's scale*, in which the same space is divided into 80 equal parts, called *degrees;* and *Fahrenheit's scale*, in which this space is divided into 180 equal parts, also called *degrees*.

In the centigrade scale, the freezing point is marked 0, and the degrees are numbered both up and down, the former numbers being considered positive, and designated by the sign +, whilst the latter are considered negative, and designated by the sign –. Of course the boiling point is marked 100°.

Fig. 134 represents a thermometer mounted and graduated according to the centigrade scale. In it the mercury indicates 30° C.

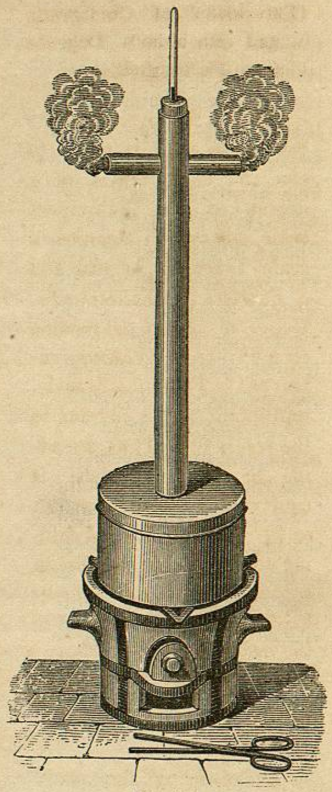


Fig. 133.

In Reaumur's scale, the freezing point is marked 0, and the boiling point 80°. The degrees below freezing are marked as in the centigrade scale.

In Fahrenheit's scale, which is the one most used in the United States, the 0 point is taken 32° below the freezing

Where is the 0 point of the centigrade scale? Explain the signs + and –. What is the boiling point marked? Where is the 0 of the Reaumur scale? The boiling point? Where is the 0 of Fahrenheit's scale?

point, and the divisions are numbered from this point both up and down. The boiling point of distilled water is, then, 212° F.

Conversion of Centigrade and Reaumur's Degrees into Fahrenheit's.

185. A degree on the centigrade scale is equal to one and eight tenths of a degree on the Fahrenheit scale, and one on Reaumur's scale is equal to two and a quarter on Fahrenheit's. Hence, to convert the reading on a centigrade to an equivalent one on Fahrenheit's scale, multiply it by 1.8 and add to the result 32°. Thus, a reading of 25° centigrade, is equivalent to $25° \times 1.8 + 32°$, or 77° F. To convert a reading on Reaumur's scale to an equivalent one on Fahrenheit's, multiply by $2\frac{1}{4}$, and to the result add 32°. Thus, a reading of 24° Reaumur is equivalent to $24° \times 2\frac{1}{4} + 32°$, or 86° F.

By reversing the above processes, readings on Fahrenheit's scale may be converted into equivalent ones on the centigrade or Reaumur's scale.

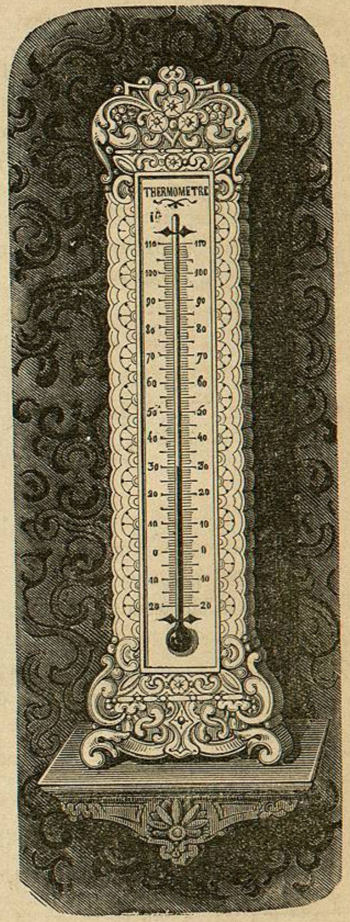


Fig. 134.

The boiling point? (**185.**) *Explain the method of converting readings from one scale to another.*

Alcohol Thermometers.

186. An ALCOHOL THERMOMETER is similar to a mercurial one in all respects, except that alcohol, tinged red, is used in place of the mercury.

Because alcohol does not expand regularly with a regular increase of temperature, the alcohol thermometer has to be graduated by experiment, comparing it degree by degree with a standard mercurial thermometer.

An alcohol thermometer is more easily filled than a mercurial one, no funnel being required. The bulb is heated until a portion of the contained air is driven off, and then the open end of the tube is plunged into a vessel of alcohol. As the air in the bulb cools, the pressure of the external atmosphere forces a portion of alcohol up into the bulb. If this be boiled, the vapor of alcohol will expel the remainder of the air, and by dipping the open end of the tube into the alcohol once more, the bulb will be completely filled, when it again becomes cool. The instrument is then treated like the mercurial thermometer.

Relative advantages of Mercurial and Alcohol Thermometers.

187. For ordinary purposes, the mercurial thermometer is to be preferred, on account of the uniformity with which the mercury expands with a uniform increase of temperature. But mercury congeals at 39° below 0 of the Fahrenheit scale, and where a lower temperature than this is to be observed, it becomes absolutely necessary to employ the spirit thermometer. In the severe cold of the polar regions, mercury often congeals, but no degree of cold has yet been obtained that will congeal absolute alcohol.

For high temperatures, mercury is alone capable of being used; this liquid does not boil till raised to 662° F., whilst alcohol boils at 174° F. The latter liquid can not, therefore, be used to observe temperatures higher than 174° F., nor can it be relied upon even for temperatures considerably lower than this.

It is to be observed, that mercury can not be relied upon for temperatures lower than 32° below 0, on account of irregularities in its rate of contraction below that limit.

(**186.**) How does the alcohol differ from the mercurial thermometer? *How is the alcohol thermometer graduated? Why? How is it filled?* (**187.**) *When is the alcohol thermometer preferable to the mercurial one? When must the latter be used?*

Rules for using a Thermometer.

188. Before noting the height of the mercurial column, the instrument should be allowed to acquire the temperature of the medium in which it is placed. This, in general, will require some minutes.

In determining the temperature of a room, the thermometer should not be hung against the walls, but should be freely suspended, so as to take the temperature of the atmosphere. When hung against a wall, especially an outer wall, an error of several degrees might result. In like manner, if hung against a wall containing a flue, or adjoining another room of different temperature, a similar error of several degrees might result.

To determine the temperature of the atmosphere, the thermometer should be freely suspended in the air at some distance from any building or tree. It should be sheltered from the direct action of the sun's rays, as well as from the influence of reflecting substances. Furthermore, it should be protected from winds and currents of air.

The Differential Thermometers.

189. A DIFFERENTIAL THERMOMETER is a thermometer contrived to show the difference of temperature between two places near each other. The two principal forms of the differential thermometer are RUMFORD'S and LESLIE'S.

When can the former only be used? (**188.**) What precautions are to be taken in noting the temperature of a room? Why? In noting the temperature of the atmosphere? (**189.**) What is a Differential Thermometer? What are its two forms?

Rumford's Differential Thermometer.

190. RUMFORD'S DIFFERENTIAL THERMOMETER is represented in Fig. 135.

It consists of two bulbs of thin glass, *A* and *B*, connected by a fine tube bent twice at right angles, as shown in the

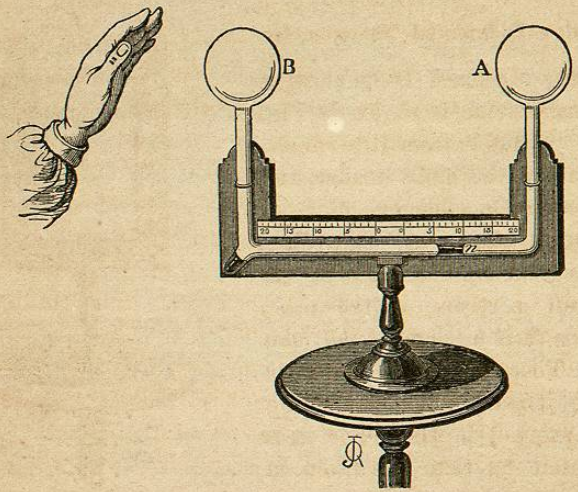


Fig. 135.

figure. The whole apparatus is attached to a suitable frame, which supports a scale parallel to the horizontal branch of the connecting tube. The 0 of the scale is at its middle point, and the graduation is continued from it in both directions. The bulbs and a large part of the connecting tube are filled with air; there is, however, in the tube a small drop of fluid which separates the air in the two extremities.

The instrument is so constructed that the index, *n*, is at the 0 of the scale when the temperature of the two bulbs is

(**190**) Describe RUMFORD'S form. Explain the scale. Explain its action. How is the scale graduated?

the same. When one of the bulbs is heated more than the other, the air in it expands and drives the index towards the other, until the tensions of the air in the two bulbs exactly balance each other.

The scale is divided by experiment by the aid of a standard mercurial thermometer.

Leslie's Differential Thermometer.

191. LESLIE'S DIFFERENTIAL THERMOMETER is shown in Fig. 136. It differs from RUMFORD'S, in having the bulbs smaller, and in containing a longer column of liquid in the tube. The scales are placed by the sides of the vertical portions of the tube, having their 0 points at the middle. There is, then, a double scale. The method of graduating and using this thermometer is the same as that described in the last article.

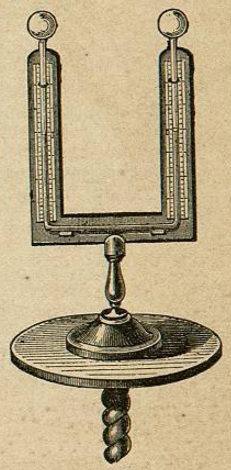


Fig. 136.

Pyrometer.

192. A PYROMETER is an instrument for measuring higher temperatures than can be observed by means of the mercurial thermometer.

The most important pyrometers are those of WEDGEWOOD and BROGNIART. The former is founded on the diminution of the volume of clay at high temperatures, and the latter on the principle of the expansion of metals. The indications of these instruments are very unreliable, and it yet remains

(**191**.) Describe LESLIE'S Differential Thermometer. (**192**.) What is a Pyrometer? What are the most important ones? What is the principle of each? Are they reliable?