The reason of this is, that the former are good conductors, and readily abstract the animal heat from the hand, whilst the latter are bad conductors, and do not convey away the heat of the hand.

Wooden handles are sometimes fitted to metallic vessels which are to contain heated liquids. This is because wood is a bad conductor, and therefore does not convey the heat to the hand. For a similar reason, when we would handle any heated body, we often interpose a thick holder of woollen cloth, the latter being a bad conductor.

To preserve ice in summer, we surround it with some bad conductor, as straw, sawdust, or a layer of confined air. The same means are adopted to preserve plants from the action of frost. In this case, the non-conducting substance prevents the radiation of heat.

Cellars are protected from frost in winter by a double wall inclosing a layer of air, which is a non-conductor. It is the layer of confined air that renders double windows so efficient in excluding frost from our houses.

The feathers of birds and the fur of animals are not only in themselves bad conductors, but they inclose a greater or less quantity of air, which renders them eminently adapted to the exclusion of cold.

The bark of trees is a bad conductor, and so serves to protect them from the injurious effects of heat in summer, and cold in winter.

Our warmest articles of clothing are composed of non-conducting substances, inclosing a greater or less quantity of air. Such are furs, woollen cloths, and the like. It is not that these are warm of themselves, but they serve as non-conductors, preventing the escape of animal heat from our bodies.

V.—LAWS OF EXPANSION OF SOLIDS, LIQUIDS, AND GASES.

ws of Expansion of Solids.

208. Numerous experiments have been made to determine the exact amount of expansion which bodies experience

Why are wooden handles attached to metallic vessels? How is ice preserved in summer? Why? How are plants protected? Why? How are cellars protected from frost? Why? Why are feathers adapted to exclude cold? Bark of trees? What substances form the warmest clothing? Why?

by the addition of a given amount of heat. As in a former article, it will be found convenient to consider first, *linear expansion*, and afterwards, *expansion in volume.*

1. *Linear expansion.* In order to compare the rate of linear expansion of different bodies, we take for a term of comparison, the expansion experienced by a unit of length of each body when heated from 32° F. to 33° F. This is called *the coefficient of linear expansion.*

The coefficients of linear expansion for a great number of bodies were determined in the latter part of the last century by Lavoisier and Laplace. They reduced the substance to be experimented upon to the form of a rod or bar, then exposed it for a sufficient time to the temperature of melting ice, and measured its exact length. They next exposed the bar to a temperature of boiling water, and again measured its length. The increased length, divided by 180, gave the increase in length of the whole bar for 1° F. This result, divided by the length of the bar at 32° F., gave the linear expansion of a unit of length, and for an increase of temperature of 1° F., that is, *the coefficient of linear expansion.*

The following are some of the results thus obtained:

SUBSTANCE.	COEFFICIENT.	SUBSTANCE.	COEFFICIENT.
Glass	0.00000478	Brass	0 00000954
Platinum	0.00000491	Copper	0.00001043
Steel	0.00000599	Silver	0.00001061
Iron	0.00000678	Lead	0.00001587
Gold	0.00000814	Zinc	0.00001634

From the above table, it is seen that the amount of expansion is always very small.

(**208.**) What is the coefficient of linear expansion of solids? How determined by Lavoisier and Laplace? *Give some of the results?*

2. *Expansion in volume.* The *coefficient of expansion in volume* is the increment which a cubic unit of the substance experiences when its temperature is raised 1° F. This coefficient may be determined experimentally, or it may be found by multiplying its coefficient of linear expansion by 3.

Applications.

209. The principle of expansion explains many familiar phenomena, some of which are indicated below.

When hot water is suddenly poured into a cold tumbler, it often breaks. In this case the explanation is simple. Glass is a bad conductor of heat, hence the inside becomes heated by contact with the water more rapidly than the outside, and this inequality of heating produces an inequality of expansion that ruptures the glass. The thinner the glass, the less will be the inequality of expansion, and consequently the less will be the danger of rupture. In a metallic vessel such an accident is not to be apprehended, because metals are good conductors, and but little, if any, inequality of expansion can arise.

When a candle is held too near a pane of glass, it oftentimes causes it to break; the reason is the same as before.

Sometimes a vessel of glass is suddenly broken by opening a door or window. This is due to a current of cold air which, falling upon the outer surface of the glass, causes an inequality of contraction that may produce rupture. All articles of glass should be guarded from sudden changes of temperature, would we avoid risk of breakage.

In the art of engineering, it is important to take into account the expansion and contraction of the metals. In laying the track of a railroad, for example, the rails should not be laid so as to touch each other, otherwise in warm weather the expansion, acting through a long line, might produce a force sufficient either to bend the rails or

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What is the coefficient of expansion in volume? How determined? (**209.**) *Why does hot water break a cold tumbler? Which is most easily broken, a thin glass or a thick one? Why? Why is a pane of glass broken by the approach of a candle? Why may a glass vessel be broken by opening a door or window? Precautions? Explain the effect of expansion on a line of rails.*

to tear them from their fastenings. In employing iron ties in building, arrangements should be made by means of nuts and screws to tighten them in warm weather, and loosen them in cold weather, otherwise the forces of contraction and expansion would weaken and eventually destroy the building. Very serious accidents have occurred from omitting this precaution.

The principle of expansion and contraction of metals has been utilized in bringing the walls of a building together after they have commenced to separate. A system of iron ties is formed, passing through the opposite walls, on the outside of which they are secured by nuts. The alternate rods being heated, they expand, and the nuts are screwed up close to the walls. On cooling, the force of contraction brings the walls nearer together. The remaining rods are next heated, and the nuts screwed up. On cooling, a further contraction takes place, and so on until the walls are restored to their proper position. This method was successfully employed to restore the walls of a portion of the *Conservatoire des Arts et Metiers*, in Paris, which had begun to separate.

Compensating Pendulum.

210. The construction of the *Compensating Pendulum* depends upon the principle of contraction and expansion of metals. We have seen already that the time of oscillation of a pendulum depends upon its length, vibrating faster when shortened, and slower when lengthened. In consequence of variations of temperature, if a pendulum were suspended by a single metallic rod, its rate of vibration would be continually changing.

To obviate this defect and secure uniformity of rate, various devices have been employed, one of the most important of which is HARRISON's Gridiron Pendulum, shown in Fig. 144. It consists of five parallel bars of metal, arranged as shown in the figure. The bars *a*, *b*, *c*, and *d*, are of steel, and when they expand, the effect is to lengthen the pendulum; the bar, *d*, passes freely through the cross piece, *or*, and is firmly attached to the piece, *mn*. The bars,

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Precautions to be taken in building with iron? Explain the method of straightening walls. (**201.**) *What effect has heat upon a pendulum? How are its defects remedied? Explain the theory and construction of* HARRISON's *Gridiron Pendulum.*

h and *k*, are of brass, firmly attached to both of the cross pieces, *mn* and *or*. When they expand, the effect is to raise the piece, *mn*, and thus to shorten the pendulum.

If the pieces are properly adjusted, the amount of shortening is exactly equal to he amount of lengthening before mentioned, and these two balancing each other, the length of the pendulum remains invariable. The adjustment requires that the lengths of the rods should be inversely as their coefficients of linear expansion.

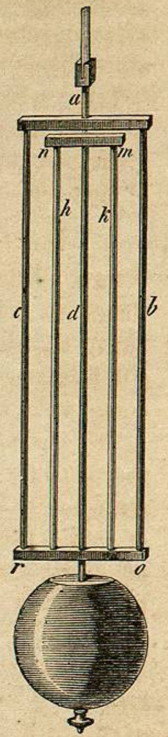

Fig. 144.

Laws of Expansion of Liquids.

211. Liquids are much more expansible than solids, on account of their feeble cohesion; their expansion is also much more irregular, especially when their temperature approaches the boiling point.

The expansion of a liquid may be *absolute* or *relative*. The absolute expansion of a liquid is its actual increase of volume; the relative expansion is its increase of volume with respect to the containing vessel. For example, in a thermometer the rise of the liquid in the stem is due to its relative expansion, with respect to that of the stem. Both expand, but the liquid more rapidly than the glass. The capacity of the bulb increases with an increase of heat, but the volume of its contained mercury increases more rapidly, and therefore rises in the stem. The absolute is generally greater than the relative expansion. It is the relative expansion that we generally observe.

(**211.**) Why are liquids more expansible than solids? What is absolute expansion? Relative expansion? Example. Which is generally observed?

The *coefficient of expansion* of a liquid is the expansion of a unit of volume, corresponding to an increase of temperature of one degree.

Taken with reference to glass, the coefficient of expansion for mercury is 0.000833; that of water is three times as great, and that of alcohol nearly eight times as great as that of mercury.

Maximum Density of Water.

212. If water is cooled down gradually, its volume continues to contract until it reaches the temperature of 38°.75 F., when it attains its maximum density. If it be still further cooled it begins to expand, and at 32° F. it becomes solid, or *freezes*.

This curious phenomenon may be shown by using a water thermometer in connection with a mercurial one. As the temperature is diminished, the liquids descend in the stems of both thermometers until the mercurial one shows 38°.75 F., after which, if the cooling process be continued, the mercury will continue to fall, whilst the water will begin to rise.

This apparent exception to the law of expansion and contraction is explained from the fact, that at the temperature of 38°.75 F. the particles begin to arrange themselves in a new order, preparatory to taking a crystalline form. Some other substances, such as melted iron, sulphur, bismuth, &c., exhibit a similar expansion of volume immediately previous to taking a solid crystalline form. It is this property of expanding at the time of crystallization, that renders iron so valuable a metal for casting. The expansion of the metal acts to fill the mould, thus giving sharpness and accuracy to the casting.

What is the coefficient of expansion of a liquid? What is its value for mercury with reference to glass? How do the coefficients of water and alcohol compare with mercury? (**212**) At what temperature has water the greatest density? When does it freeze? How may the phenomenon be shown? How explained? What other bodies exhibit similar phenomena? Why is iron so valuable for casting?

The fact that water has its greatest density at 38°.75 F., causes ice to form at the surface instead of at the bottom of rivers and lakes. Were it not that ice is lighter than water, it would sink to the bottom as fast as formed, or rather would form at the bottom, and in the colder regions of the globe would soon convert entire lakes into solid masses of ice. As ice and water are bad conductors of heat, the summer sun would not posesss the power to convert them again into water.

In Switzerland it is found by experiment that the temperature of the water at the bottom of deep and snow-fed lakes remains during the entire year at the uniform temperature of 38°.75 F., although the surface is frozen in winter, and in summer rises to 75° or 80° F.

It is because water has its maximum density at 38°.75 F., that it is taken at this temperature, as the standard of comparison for determining the specific gravity of bodies.

Law of expansion of Gases.

213. Gases are not only more expansible than solids and liquids, but they also expand more uniformly.

The *coefficient of expansion* of a gas, is the expansion which a unit of volume experiences when its temperature is increased one degree.

Gay Lussac supposed that all gases expanded equally for equal increments of temperature; but more recent investigations show that the coefficients of expansion are slightly different for different gases. This difference is, however, so small, that for all practical purposes we may regard all gases as having the same coefficient. The value of the coefficient of expansion for gases is 0.00204, which is about eight times that of water.

Applications.

214. The law of expansion of gases when heated, has many important applications, some of which will be indicated.

Explain the consequences of the expansion of water on freezing. Example of the lakes in Switzerland. Why is water taken at 38°.75 F. as a standard? (**213.**) What bodies are most expansible? What is the coefficient of expansion? What was Gay Lussac's opinion? Was it strictly correct?

When the air of a room becomes warmed and vitiated by the presence of a number of persons, it expands and becomes lighter than the external air; hence it rises to the top of the room, and its place is supplied by fresh air from without, which enters through the cracks of the doors, or through apertures constructed for the purpose. Openings should be made at the upper part of the room to permit the foul air to escape. Such is the theory of *ventilation* of rooms.

In large buildings, like theatres, the spectators in the upper galleries often experience great inconvenience from the hot and corrupt air arising from below. To remedy this evil, large openings, called ventilators, should exist in the upper ceiling, and corresponding openings should be arranged near the bottom of the building to supply a sufficient quantity of fresh air to keep up the circulation.

The principal of expansion gives a draft to our chimneys. The hot air ascends through the flue, and its place is supplied by a continued current of cold air from below, which keeps up the combustion in the fire-place or grate.

The same principle is applied in warming buildings by means of furnaces. Furnaces are placed in the lowest story of the building, and are provided with air chambers, which communicate with the external air by means of air-pipes. When the air becomes heated in the air chamber, it rises through pipes, or flues in the walls, to the upper stories of the building, and is admitted to or excluded from the different apartments by valves, called *registers*.

The principle of expansion of air explains many meteorological phenomena. When the air in any locality becomes heated by the rays of the sun, it rises and its place is supplied by colder air from the neighboring regions, thus producing the phenomena of winds. The circulation of the atmosphere in the form of winds, tends to equalize the temperature, and also, by transporting clouds and vapors, tends to equalize the distribution of water over the globe.

Winds also serve to remove the vitiated air of cities, replacing it by the pure air of the neighboring places, thus contributing to the preservation of life and health. Winds also act to propel vessels on

(**214.**) *How does the principle of expansion operate in ventilation? How are large buildings ventilated? What gives draft to chimneys? Explain the theory of heating by furnaces. How does the principle of expansion produce winds? Their effect on distribution of warmth and moisture?*

the ocean, thus contributing to the spread of commerce and civilization.

Without winds, our cities would become centres of infection, the clouds would remain motionless over the localities where they were formed, the greater portion of the earth would become arid and desert, without rivers or streams to water them, and the whole earth would soon become uninhabitable.

Density of Gases.

215. The density of a gas depends upon the pressure to which it is subjected, and also upon its temperature.

It is for this reason that we select as a term of comparison the density at some particular pressure and temperature. The standard pressure is that of the atmosphere when the barometer stands at 30 inches, and the standard temperature is 32° F., or the freezing point of water. To determine the density at any other pressure, we apply MARIOTTE'S law; to determine it at any other temperature, we apply the coefficient of expansion, as explained in preceding articles.

Suppose it were required to determine the density of air when the barometer indicates 20 inches, and the thermometer 62° F., the density being equal to 1 at the standard temperature and pressure. The pressure being only two thirds the standard pressure, the air in the case considered would occupy once and a half its primitive volume, supposing the temperature to remain at 32° F. But the temperature being 62° F., we must increase this by 0.00204 times its volume at 32°. Hence the volume becomes 1.5 increased by 1.5 × 0.612, or 1.5 + 0.0918, or, finally, 1.5918. That is, a unit of volume at the standard pressure and temperature becomes 1.5918 units of volume at the given pressure and temperature. Because the density varies inversely as the volume, we shall have for the required density, $\frac{1}{1.5918}$, or 0.6282.

Other effects of winds? (**215.**) On what does the density of a gas depend? What do we take as a standard? How do we determine the density at any other pressure and temperature? *Example.*

The following table exhibits the density of some of the most important gases, air being taken as a standard:

TABLE.

GAS.	DENSITY.	GAS.	DENSITY.
Air	1.0000	Oxygen	1.1056
Hydrogen	0.0692	Carbonic acid	1.5290
Nitrogen	0.9714		

Hydrogen is the lightest known body, its density being fourteen and a half times less than that of air.

VI.—CHANGE OF STATE OF BODIES BY THE ACTION OF HEAT.

Fusion.

216. It has been stated that heat not only causes bodies to expand, but that it may in certain circumstances cause them to change them from the solid to the liquid, or from the liquid to the gaseous state.

When a body passes from a solid to a liquid state, it is said to *melt*, or *fuse*, and the act of changing state in this case is called *fusion*.

If a melted body is suffered to cool, it becomes solid at the same temperature at which it melted. Hence the melting point is the same as the freezing point.

Fusion takes place when the force of cohesion, which holds the particles of a body together, is exactly balanced by the heat which tends to separate them. The temperature at which fusion takes place is different for different bodies. For some bodies it is very low, and for others very high, as is shown in the following

What is the lightest body? Give the densities of some other gases. (**216**) What is melting or fusion? *When does fusion take place? Is the melting point the same for all solids?*

TABLE.

BODY.	TEMPERATURE OF FUSION.	BODY.	TEMPERATURE OF FUSION.
Mercury	39° F.	Bismuth	507° F.
Ice	32°	Lead	635°
Tallow	91°	Antimony	842°
White wax	149°	Zinc	932°
Sulphur	232°	Silver	1832°
Tin	442°	Gold	2192°

All bodies are not melted by the action of heat. Some are decomposed, such as paper, wood, bone, marble, &c. Simple bodies, that is, bodies which are composed of but one kind of matter, always melt, if sufficiently heated, with a single exception. Carbon has thus far resisted all attempts to fuse it.

Latent Heat of Fusion.

217. Bodies which can be melted always present the remarkable phenomenon, that when they are heated to the temperature of fusion, they can not be heated any higher until the fusion is complete. For example, if ice be exposed to heat, it begins to melt at 32° F., and if more heat be applied, the melting is accelerated, but the temperature of the mixture of ice and water remains at 32° until all the ice is melted.

The heat that is applied during the process of fusion, enters into the body without raising its temperature, and is said to become *latent*. When the body returns to its solid state, all the latent heat is again given out, and once more becomes *sensible*.

The phenomenon of latent heat may be illustrated by the following experiment. If a pound of pulverized ice, at 32° F., be mixed

Examples. Are all bodies melted by the action of heat? Examples. (**217**.) What is latent heat? Sensible heat? *How may the phenomenon of latent heat be illustrated.*

with a pound of water at 174° F., the heat of the water will be just sufficient to melt the ice, and there will result two pounds of water at the temperature of 32° F. During the process of melting, 142° of heat have been absorbed and become latent; hence, we say that the heat required to freeze water at 32° F. is 142°, or, in other words, the latent heat of water at 32° is 142°.

The enormous amount of heat which becomes latent when ice melts, explains why it is that large masses of ice remain unmelted for a considerable time after the temperature of the air is raised above 32° F. Conversely, the immense quantity of heat absorbed when water passes to the state of ice, explains why it is that ice forms so slowly in extremely cold weather. The absorption of heat in melting, and production of heat in freezing, tend to equalize the temperature of climates in the neighborhood of large masses of water, like lakes and rivers.

Congelation.—Solidification.

218. Any body that can be melted by the application of heat, can be brought back to a solid state by the abstraction of heat. This passage from a liquid to a solid state is called *congelation*, or *solidification.*

In every body, the temperature at which congelation commences, is the same as that at which fusion begins. Thus, if water be cooled, it will begin to congeal at 32° F., and conversely, if ice be heated, it will begin to melt at 32° F. Furthermore, the amount of heat given out, or rendered sensible in congealing, is exactly equal to that absorbed, or rendered latent in melting.

Some liquids can not be congealed by the greatest cold to which we can subject them; such are alcohol and ether. Pure water congeals at 32°; the salt water of the ocean congeals at 27°; olive oil at 21°; linseed and nut oils at 17°.

Explain the action of latent heat on melting masses of ice. Also on freezing masses of water. (**218**.) What is congelation? How does the point of congelation compare with that of fusion? Illustrate. How does the heat given out in solidifying compare with that taken up in melting? *What liquids have never been frozen?*

Water reaches its maximum density at 38°.75, and as its temperature is diminished from this limit, its volume continues to increase until congelation is completed. This increase of volume takes place with an expansive force capable of bursting the strongest vessels. Hence, in cold weather, water should not be left in vessels and pipes, or in any apparatus which might be broken by frost.

On account of this expansion of water in congealing, it follows that it is less dense than before; hence it is that ice floats on the surface of water. In the polar regions immense masses of floating ice, called icebergs, are continually seen. Some of these are of immense height, and extend to a corresponding depth in the water. In passing shoal places, they often become stranded, and remain fixed until, by gradual melting, their volume is sufficiently reduced to permit them to float clear of the bottom.

Crystallization.

219. When bodies pass slowly from the liquid to the solid states, their particles, instead of arranging themselves in a confused manner, tend to group themselves into regular forms. These forms are called *crystals*, and the process of forming them is called *crystallization.*

Flakes of snow, sugar candy, alum, common salt, and the like, offer examples of crystallized bodies. The forms of the crystals are best seen under a magnifying glass.

Bodies may be crystallized in two different ways. In the first case, we melt them, and then allow them to cool slowly. If a vessel of sulphur be melted and allowed to cool slowly, it will commence crystallizing about the surface, and if we break the crust thus formed, and pour out the interior liquid sulphur, we may obtain beautiful crystals of sulphur.

In the second case, we dissolve the body to be crystallized and then allow the solution to evaporate slowly. The dissolved body is then deposited at the bottom and on the

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Why are vessels often burst by the freezing of water in them? Precautions? Why does ice float? Explain the phenomenon of icebergs. (**219.**) What are crystals? What is crystallization? Examples. How many methods of crystallization? Explain the first method? The second method?

sides of the vessel in the form of crystals. The slower the process, the finer will be the crystals. It is in this manner that we crystallize candy and various salts.

Freezing Mixtures.

220. The absorption of heat which takes place when a body passes from a solid to a liquid state, is often utilized in the production of intense cold. This result is best obtained by mixing certain substances, and these mixtures are then called *freezing mixtures.*

A mixture of one part of common salt and two parts of pounded ice forms a mixture that is used for freezing cream. The salt and ice have an affinity for each other, but they can not unite until they pass to the liquid state; in order to pass to this state they absorb a great quantity of heat from the neighboring bodies, and this causes the latter to freeze. By means of a mixture of salt and snow, the thermometer may be reduced to 0.

VII.—VAPORIZATION.—ELASTIC FORCE OF VAPORS.

Vaporization.—Volatile and Fixed Liquids.

221. When sufficient heat is applied to a liquid, it is converted into a gaseous form and is called a *vapor.* The change of state from a liquid to a gaseous state is called *vaporization.*

Conversely, if heat be abstracted from a vapor, it will return to a liquid form. The change of state from a vaporous to a liquid form is called *condensation.*

Vapors are generally colorless, and are endowed with an *expansive force*, or *tension*, which, when heated, may become very great.

(**220.**) What is a freezing mixture? Example. Explain its action? (**221.**) What is vaporization? Condensation? General properties of vapors?