

but it is thought the method will be more readily comprehended by giving *all* the details of the computation.

The small valves are therefore efficient between the limits $x=0$ and $x=120^\circ$, and the engine may be stopped by means of the expansion gear. By contracting these limits the ports may be made smaller. For instance, if it is not required to cut off the steam below $\frac{1}{4}$ th the stroke from commencement, *i. e.* to expand the steam more than through three-fourths the stroke, the value of v may be diminished by the value d has for $x=60^\circ$. b will be diminished by twice the value d has for $x=60^\circ$.

The above dimensions are by no means meant for a criterion, since the *assumptions* must vary with the case and judgment of the designer; but are simply used as an illustration—although correct for the assumed conditions.

Naval Academy, Newport, R. I., Jan. 25, 1864.

An Account of some Researches on Radiant Heat. By JOHN TYNDALL, Esq., F.R.S., Prof. Nat. Phil., Royal Inst.

In his former researches on the radiation and absorption of heat by gaseous matter, the speaker compared different gases and vapors at a common thickness with each other; one part of his present object was to compare different thicknesses of the same gaseous body with each other as to their action upon radiant heat. A few years ago he would be deemed a bold man who would attempt to measure the action of an inch, or indeed of many feet of a gas, on radiant heat; but the present experiments commence with plates of gas only 0.01 of an inch in thickness, and extend to thicknesses of 49.4 inches. Thus, the greatest thickness is to the least nearly in the ratio of 1 to 5000. The apparatus employed for the smaller thicknesses was a hollow cylinder, one end of which was closed by a plate of rock-salt. Into this fitted a second cylinder, with its end also closed by a plate of the salt. One cylinder moved within the other like a piston, and by this means the two plates of salt could be brought into flat contact with each other, or could be separated to any required distance. The distance between the plates was measured by a *vernier*. The cylinder was placed horizontal, being suitably connected with a source of heat. This latter consisted of a plate of copper, against which a steady sheet of flame was caused to play.

The absorption of radiant heat by carbonic oxide, carbonic acid, nitrous oxide, and olefiant gas was determined with this apparatus, and such differences as might be anticipated from former researches were found. Olefiant gas maintained its great superiority over the other gases at all thicknesses. A layer of this gas, not more than 0.01 of an inch in thickness, intercepted about 1 per cent. of the total radiation; and the delicacy of the apparatus may be inferred from the fact that this absorption—great, relative to the thickness of the layer of gas, but small absolutely—corresponded to a deflection of 11 degrees of the galvanometer. (It would be certainly possible to measure the

action of a layer of this gas of less thickness than the paper on which these words are printed.) A layer of olefant gas, 2 inches in thickness, intercepts nearly 30 per cent. of the entire radiation. The influence of a diathermic envelope surrounding a planet may be strikingly illustrated by reference to this gas. A shell of olefant gas, 2 inches thick, surrounding the earth, would offer no appreciable hindrance to the solar rays in their earthward course; but it would intercept, and in great part return, 30 per cent. of the terrestrial radiation; under such a canopy the surface of the earth would probably be raised to a stifling temperature. A layer of the gas, $\frac{3}{16}$ of an inch thick, intercepts 11.5 per cent. of the whole radiation. Such a layer, if diffused through a stratum of air 10 feet thick, would be far more attenuated than the aqueous vapor actually diffused through the air; still it would produce an absorption greater than that which the speaker had assigned to the atmospheric vapor within 10 feet of the earth's surface. In the presence of such facts, the arguments which we might be disposed to base on the smallness of the quantity of atmospheric vapor are entirely devoid of weight.

In measuring the action of larger thicknesses of gas, the following method was pursued:—A brass cylinder, 49.4 inches in length, had its two ends stopped with plates of rock-salt, and a suitable source of heat placed at one end; the rays from this source passed through the tube, and were received by a thermo-electric pile placed at its opposite end; this radiation was exactly neutralized by the heat emitted from a cube of boiling water and incident on the opposite face of the pile. The interception of any portion of the heat emanating from the source by a gas or vapor introduced into the tube destroyed the equilibrium previously existing, and the amount intercepted was declared by the galvanometer. The thickness traversed by the calorific rays was varied in the following way:—The tube was divided into two distinct compartments by the introduction of a third plate of rock-salt. Let us agree to call the compartment most distant from the pile the *first chamber*, and that adjacent to the pile the *second chamber*. The experiments began with the first chamber short and the second chamber long, and ended with the first chamber long and the second chamber short. The alteration consisted solely in the shifting of the intermediate plate of salt, which lengthened the first chamber and diminished the second one by the same quantity; the sum of the lengths of both chambers being the constant quantity, 49.4 inches.

The absorption effected in the first chamber acting alone was first determined; then the absorption effected in the second chamber acting alone; and, finally, the absorption effected when both the chambers were occupied by the gas or vapor. This arrangement enabled the speaker to check his experiments, and also to examine the effect of the *shifting* which occurred in the first chamber on the absorption of the second one. The thermal coloration of the various gases was rendered strikingly manifest by these experiments. For the vast majority of the rays, for example, carbonic oxide and carbonic acid are transparent. Placing a stratum of carbonic oxide, 8 inches in length, in front

of a column of the same gas, 41.4 inches long, these 8 inches intercepted 6 per cent. of the whole radiation; placed *behind* a column 41.4 inches long, the absorption of the same 8 inches was sensibly *nil*. So also with carbonic acid; 8 inches in front absorbed $6\frac{1}{4}$ per cent., while placed behind the effect was almost zero. Similar remarks apply to the other gases, the reason manifestly being that when the 8-inch stratum is in front, it stops the main portion of the rays which give it its thermal color, while, when it is placed behind, these same rays have been almost wholly withdrawn, and to the remaining 94 per cent., or thereabouts, of the radiation the gases are sensibly transparent.

An extension of this reasoning enables us at once to conclude, that the sum of the absorption of the two chambers taken separately must always be greater than the absorption effected by a single column of the gas of a length equal to the sum of the two chambers. This conclusion is illustrated in a striking manner by the experiments; and it is further found that when the mean of the sums of the absorption is divided by the absorption of the sum, the quotient is sensibly the same for all gases. It may also be inferred from considerations similar to the foregoing, that the sum of the absorptions must diminish, and approximate to the absorption of the sum, as the two chambers become more unequal in length, and that the sum of the absorptions of the two chambers is a maximum, when the medial rock-salt plate divides the long tube into two equal compartments.

In these days a special interest attaches itself to the radiation of any gas through itself or through any other gas having the same period of vibration. The speaker referred to the results of an elaborate series of experiments on this interesting question. The experimental tube, 49.4 inches long, was divided into two compartments by a partition of rock-salt. All external sources of heat were abolished, and the pile, furnished with its conical reflector, stood at the end of the tube. The compartment nearest the pile contained the gas which was to act as absorber, while that most distant from the pile held the gas which was to act as radiator. It is known that the destruction of the motion of a sensible mass of matter is always accompanied by the evolution of heat. A weight falling to the earth, and a ball striking a target, are heated on collision. The same is true for atoms, and in the present experiment the gas in the radiating chamber was heated by the collision of its own particles against the inner surface of the tube when they rushed in to fill the vacuum. The radiation was, in fact, what the speaker had named "dynamic radiation." The lengths of the two chambers were varied, the radiating column being lengthened and the absorbing one shortened at one and the same time; the sum of both was always the constant length 49.4 inches.

The experiments with the vapors were thus executed. Both the chambers into which the tube was divided were, in the first place, occupied by the vapor to be examined; the usual pressure being $\frac{1}{6}$ of an atmosphere. The entrance of the vapor was so slow, and its quantity so small, that the radiation due to the warming of the vapor by its own collision was insensible. The needle being at zero, dry air was

allowed to enter the chamber most distant from the pile. This air became heated dynamically, communicated its heat to the vapor, and the latter immediately discharged the heat thus communicated to it against the pile. It is quite evident, that not only does this case resemble, but that it is actually of the same mechanical character as that in which a vibrating tuning-fork is brought into contact with a surface of some extent. The fork, which before was inaudible, becomes at once a copious source of sound. What the sounding-board is to the fork, the compound molecule is to the elementary atom. The tuning-fork vibrating alone is in the condition of the atom radiating alone, the sound of the one and the heat of the other being alike insensible. But in association with sulphuric or acetic ether-vapor the elementary atom is in the condition of the tuning-fork applied to its sound-board, communicating through the molecule motion to the luminiferous ether, as the fork through the board communicates its motion to the air.

The experiments demonstrate the great opacity of a gas to radiations from the same gas. They also show in a very striking manner the influence of attenuation in the case of vapor. The individual molecules of a vapor may be powerful absorbers and radiators, but in thin strata they constitute an open sieve through which a large quantity of radiant heat may pass. In such thin strata, therefore, the vapors, as used in our experiments, were generally found far less energetic than the gases, while in thick strata the same vapors showed an energy greatly superior to the same gases. The gases, it will be remembered, were always employed at a pressure of one atmosphere.

A few striking experiments were referred to in illustration of the influence of a paper lining, or a coat of varnish or lampblack, within the experimental tube. In dynamic radiation it is not possible to do entirely away with the action of the interior surface of the tube itself. When the tube is of brass and well polished within, the entrance of the air produces a deflection of 7.5 degs., this being due to the emission from the warmed surface of the tube. A lining of paper two feet long raises the radiation sufficiently to drive the needle through an arc of 80 degrees, while a ring of paper $1\frac{1}{2}$ inches long placed within the tube radiates sufficient to urge the needle through an arc of 56 degrees.

The speaker finally examined the diathermancy of the liquids from which his vapors were derived, and the result leaves no shadow of a doubt upon the mind, that both absorption and radiation are molecular phenomena, irrespective of the state of aggregation. If any vapor is a strong absorber and radiator, the liquid whence it comes is also a strong absorber and radiator. The molecule carries its power, or want of power, through all its states of aggregation. The order of absorption in liquids and vapors is precisely the same; and the speaker looked forward with hope to the application of these results to other portions of the domain of thermotics.