493 at 32° F., it would be 492 at 31° F.,

461 at 0° F.,

and finally 0 at -461°F.,

provided the same law were to hold at indefinitely low temperatures. This we may assume to be the case with a perfect gas, although any actual gas would change its physical state long before so low a temperature were reached.

This result may be concisely expressed by saying that if we reckon temperature, not from the ordinary zero but from a point 461° below the zero of Fahrenheit’s scale, the volume of a given quantity of a gas, kept at constant pressure, is proportional to the temperature reckoned from that zero. Temperatures so reckoned are called absolute temperatures, and the point - 461° F. is called the absolute zero of temperature. Denoting any temperature according to the ordinary scale by *t,* and the corresponding absolute temperature by τ, we have

τ = *t* + 461 on the Fahrenheit scale, and τ = *t* +274 on the Centigrade scale.

Charles’s law shows that if temperatures be measured by thermo­meters in which the expanding substance is air, hydrogen, oxygen, or any other permanent gas, and, if those intervals of temperature be called equal which correspond to equal amounts of expansion, then the indications of these thermometers always agree very closely with each other, and also agree, though less closely, with the indications of a mercury thermometer. We shall see later that the theory of heat-engines affords a means of forming a thermometric scale which is independent of the properties, as to expansion, of any substance, and that this scale coincides with the scale of a perfect gas thermometer, a fact which justifies the use of the term absolute, as applied to temperatures measured by the expansion of a gas.

30. Combining laws 1 and 2, we have, for a given mass of any gas,

PV=*cτ*,

where c is a constant depending on the specific density of the gas and on the units in which P and V are measured. In what follows we shall assume that P is measured in pounds per square foot, that V is the volume of 1 lb in cubic feet, and that *τ* is the absolute temperature in Fahrenheit degrees. In air, with these units,

PV = 53·18*τ*.

31. Law 3 (Regnault). *The specific heat ai constant pressure is constant for any gas.*

By specific heat at constant pressure is meant the heat taken in by 1 lb of a substance when its temperature rises 1° F., while the pressure remains unchanged—the volume of course increasing. The law states that this quantity is the same for any one gas, no matter what be the temperature, or what the constant pressure, at which the process of heating takes place.

32. Another important quantity in the theory of heat-engines is the specific heat at constant volume, that is, the heat taken in by 1 lb of the substance when its temperature rises 1° F. while the volume remains unchanged—the pressure of course increasing. We shall denote specific heat at constant pressure by K*p* and specific heat at constant volume by K*v*. Let 1 lb of a gas be heated at constant pressure P from temperature τ1 to temperature τ2 (abso­lute). Let V1 be the volume at τ1 and V2 the volume at τ2. Heat is taken in, and external work is done by the expansion of the gas, namely—

Heat taken in = Kp,(τ2-τ1).

Work done = P(V2 - V1)=*c*(τ2 - τ1).

The difference between these quantities, or (K*p*-*c*)(τ2-τ1), is the amount by which the stock of internal energy possessed by the gas has increased during the process. We shall see presently that this gain of internal energy would have been the same had the gas passed in any other manner from τ1 to τ2.

33. Law 4 (Joule). *When a gas expands without doing external work, and without taking in or giving out heat, its temperature does not change.*

To prove this, Joule connected a vessel containing compressed gas with another vessel that was empty, by means of a pipe with a closed stop-cock. Both vessels were immersed in a tub of water and were allowed to assume a uniform temperature. Then the stop-cock was opened, the gas expanded without doing external work, and finally the temperature of the water in the tub was found to have undergone no change. The temperature of the gas was unaltered, and no heat had been taken in or given out by it.

34. Since the gas had neither gained nor lost heat, and had done no work, its internal energy was the same at the end as at the beginning of the experiment. The pressure and volume had changed, but the temperature had not. We must therefore con­clude that the internal energy of a given mass of a gas depends only on its temperature, and not upon its pressure or volume ; in other words, a change of pressure and volume not associated with a change of temperature does not alter the internal energy. Hence

in any change of temperature the change of internal energy is inde­pendent of the relation of pressure to volume throughout the opera­tion. Now we have seen above that the quantity

(K*p*,-*c*)(τ2-τ1)

measures the gain of internal energy when 1 lb of a gas has its temperature changed from τ1 to τ2 in one particular way, namely, at constant pressure. Hence this same quantity also measures the gain of internal energy when 1 lb of a gas has its temperature changed from τ1 to τ2 in any manner whatsoever.

35. Next consider the case of 1 lb of a gas heated from τ1 to τ2 at constant volume. The heat taken in is

K*v*(τ2-τ1).

Since no work is done, this is all gain of internal energy, and is therefore (§ 34) equal to

(K*p*-*c*)(τ2-τ1).

Hence in any gas

K*p*-*c*=K*v*.

The ratio K*p*∕K*v*. will be denoted by 7; obviously K*v*=*c*∕(γ -1). The following table of values of Kp, K*v*,*c*, and γ will be found useful in dealing with air and gas engines.

Table I. —*Properties of Gases.*

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | K*p*. | K*v.* | *c.* | *γ∙* |
| Dry air | Foot-lbs.  183∙4 | Foot-lbs. 130∙2 | Foot-lbs. 53∙2 | 1∙409 |
| Oxygen | 167∙9 | 119∙8 | 48∙1 | 1∙402 |
| Nitrogen | 188∙2 | 133∙4 | 54∙8 | 1∙411 |
| Hydrogen | 2632 | 1864 | 768 | 1∙412 |
| Carbonic oxide | 189∙1 | 133∙4 | 55∙7 | 1∙418 |
| Carbonic acid | 167∙4 | 132∙6 | 34∙8 | 1∙263 |
| Marsh gas | 457∙7 | 363∙1 | 94∙6 | 1∙261 |
| Olefiant gas | 311∙9 | 257∙7 | 54∙2 | 1∙213 |
| Steam gas, or highly superheated steam... | 371 | 285∙5 | 85∙5 | 1∙30 |

36. We shall now return to the consideration of diagrams like that of § 25, which exhibit the action of a working substance by curves show­ing the relation of P to V during ex­pansion or compression. In most of the instances which occur in the theory of heat-engines such curves may be ex­actly or approximately represented by equations of the form

PV*n*=constant,

where the index *n* has various numer­

ical values. Let AB, fig. 10, be a curve

of expansion (of any substance) in

which PV*n* is constant, from pressure P1 and volume V1 at A to pressure P2 and volume V2 at B. We have, by assumption,

P1V1*n*=>P2V2*n.*

The work done is

∕v⅛^-p1y1.∕v≈^=b∑0^y0.

√Vι ι∕v, V” 1-»

This may also be written

P1V1(l-r1^n) *n* -1 ’

where *r* is the ratio V2∕V1, which may be called the ratio of expansion.

Still another form of the above expression for the work done is P1V1-P2V2 *n-1*

37. Applying this result to the case of an expanding gas, we have

Work done = *c*(τ1-τ2)∕(*n*-l).

The loss of internal energy during expansion is, by § 34,

K*v*(τ1 - τ2), or *c*(τ1 - τ2) ∕ (γ-1), by § 35.

Suppose now that the mode of expansion is such that the loss of internal energy is equal to the external work done, then

⅛lξt2)^c(t1-t2) *n-1* 7-1

and the law of expansion is

PVγ= constant.

The same formula applies when a gas is being compressed in such a manner that the work spent upon the gas is equal to the gain of internal energy by the gas.

38. This mode of expansion (or compression) is termed *adiabatic.* It occurs when the working substance is neither gaining nor losing heat by conduction or radiation or internal chemical action. It would be realized if we had a substance expanding or being compressed, without chemical change, in a cylinder which (with the piston) was a perfect non-conductor of heat. In adiabatic