

Class 20: Thermodynamics

AP Physics

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Files for You to Download

Download from the school website:

1. 20-thermodynamics.pdf—This presentation. If you want to print the slides on paper, I recommend printing 4 slides per page.
2. 20-Homework.pdf—Homework assignment for Classes 19 and 20, which cover Fluid Mechanics and Thermodynamics

Please download/print the PDF file before each class. When you are taking notes, pay particular attention to things I say that aren't necessarily on the slides.

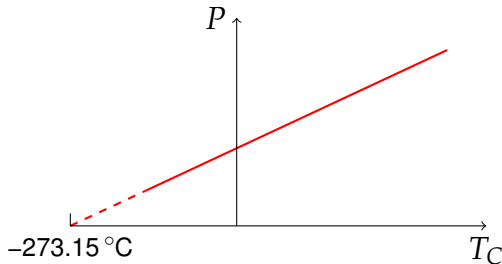
Review: Absolute Temperature Scale

aka the Kelvin Scale

Relationship between the absolute temperature scale and the Celsius scale is a constant:

$$T = T_C + 273.15$$

Plotting pressure vs. temperature at *constant volume* for gases gives a straight line that appear to intersect the x -axis at -273.15°C :



Review: Absolute Temperature Scale

$$T = T_C + 273.15$$

Quantity	Symbol	SI Unit
Absolute temperature	T	K (Kelvin)
Temperature in degree Celsius	T_C	°C is not an SI unit

- Developed by William Thomson (Lord Kelvin) and James Joule
- Until the 1960's, absolute temperature used the unit "degree kelvin"
- The temperature *change* of 1 K is the same as 1 °C
- The two scales differ in where *zero* is (called the "null point")

Thermal Expansion

When temperature T of an object with length L increases, the object *usually* expands. The *thermal strain* ($\Delta L / L$) is proportional the change in temperature:

$$\frac{\Delta L}{L} = \alpha \Delta T \quad \text{where} \quad \alpha = \frac{1}{L} \frac{dL}{dT}$$

Quantity	Symbol	SI Unit
Length	L	m (meter)
Temperature	T	K (kelvin)
Coefficient of linear expansion	α	K^{-1} (per kelvin)

α is independent of pressure for solids and liquids, but may vary with T .

Thermal Expansion

There is also a similar expression for **coefficient of volume expansion**:

$$\frac{\Delta V}{V} = \beta \Delta T \quad \text{where} \quad \beta = \frac{1}{V} \frac{dV}{dT}$$

β is also independent of pressure for solids and liquids, but may vary with T .

Quantity	Symbol	SI Unit
Volume	V	m^3 (cube meter)
Temperature	T	K (kelvin)
Coefficient of volume expansion	β	K^{-1} (per kelvin)

Careful application of calculus will show that for isotropic material (where α is the same in all direction)

$$\beta = 3\alpha$$

Ideal Gas Law for Low-Density Gases

Boyle's Law: Physicist Robert Boyle (1627-1691) discovered that, when a gas is allowed to expand or compress at *constant temperature*, the product of pressure P and V remain constant, i.e.:

$$PV = \text{constant}$$

We also know that at *constant volume*, temperature is proportional to pressure. Our equation now modifies to:

$$PV = CT$$

where “C” is some constant that is yet to be determined.

Ideal Gas Law

Thought experiment:

- Two identical containers with volume V with same amount of same kind of gas at same pressure P and temperature T .
- When the containers are combined and the molecules are free to move, P and T remain the same, but volume is increased by factor of 2.

C must scale with the number of molecules of gas N , which modifies the equation to this, the **ideal gas law**:

$$PV = NkT$$

The constant $k = 1.381 \times 10^{-23}$ J/K is called **Boltzmann's constant**. It is found experimentally to have the same value for any kind or amount of gas.

Ideal Gas Law

The ideal gas law is more often written in terms of the number of *moles* of gas n and the **universal gas constant** R :

$$PV = nRT$$

Kinetic Theory of Gases

Assumptions for the kinetic theory of gases:

1. The gas consists of a large number of molecules that make *elastic* collisions with each other and with the walls of the container.
2. The molecules are separated, on average, by distances that are large compared to their diameters, and they exert no force (gravitational, electrostatic etc) on each other except when they collide.
3. In the absence of external forces, there is no preferred position for a molecules in the container, and there is no preferred velocity vector.

Kinetic Energy

Pressure $P = F/A$ is created when gas molecules

The average kinetic energy of an ensemble of gases is given by:

$$\langle K \rangle = \frac{3}{2}NkT$$

Often it is advantageous to calculate the root mean square of velocity of the molecules, which is approximately the most statistically probable speed:

$$v_{\text{rms}} = \sqrt{\frac{3kT}{m}}$$

Real Gases

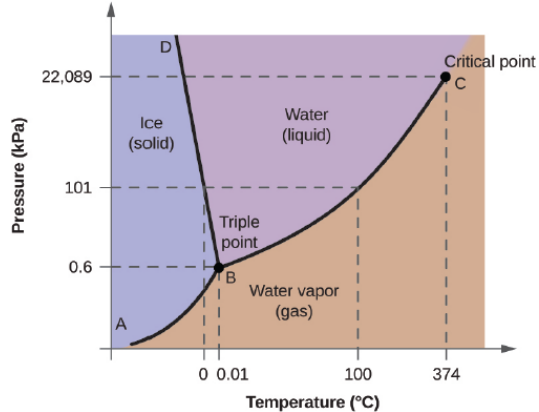
Most gases behave like ideal gas at most ordinary pressures, but the equation breaks down when the density of gas is high and molecules are not far apart:

- pressure is sufficiently high
- temperature is low

In this situation the **van der Waal equation** provides a more accurate description of the behaviour of real gases:

$$\left(P + \frac{an^2}{V^2} \right) (V - bn) = nRT$$

Phase Diagrams



First Law of Thermodynamics

$$\Delta U = Q + W$$