Lecture 10: The nature of heat

Let's get the basic concepts right:

What is heat?

What is temperature?

Heat flows from a "hotter" object to a "colder" one. In doing so, the hotter object cools and the colder object warms.

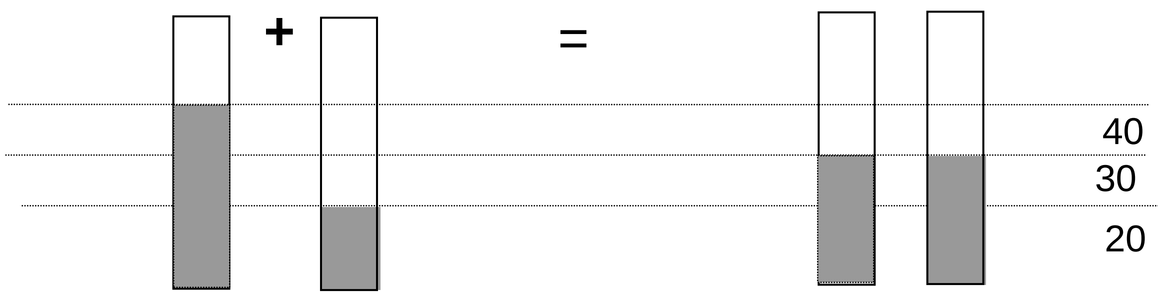
Two objects are at the same temperature when there is no heat flow between them.

This is the 0^{th} law of thermodynamics

Temperature is measured in terms of arbitrary units called *degrees*. On the Celsius scale, the temperature of melting ice is called "0" and that of boiling water "100" .

The *method of mixtures* permits a quantitative investigation of the way heat flows and of the quantity of heat required to raise the temperature of a certain object by a certain temperature.

Suppose I have 1kg of water at 20°C and 1kg of water at 40°C. If I mix them, the resulting 2kg of water will have a temperature of 30°C



Heat behaves like a fluid whose volume is conserved and which always tends to the same level - the 'caloric' theory.

The gas laws

The study of gases provided the first insights into the nature of heat because:

- the thermal properties of gases are relatively simple
- the necessary experiments were quite simple

The **steam engine** provided a link between heat and mechanical energy - through the working of gas.

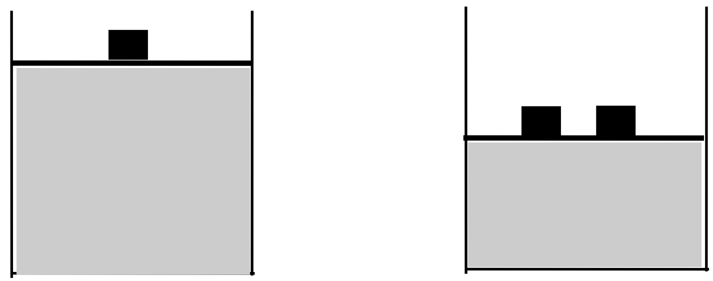
What are the attributes of a gas?

PRESSURE the force exerted per unit area. Unit: $N\ m^{-2}$ (Pa).

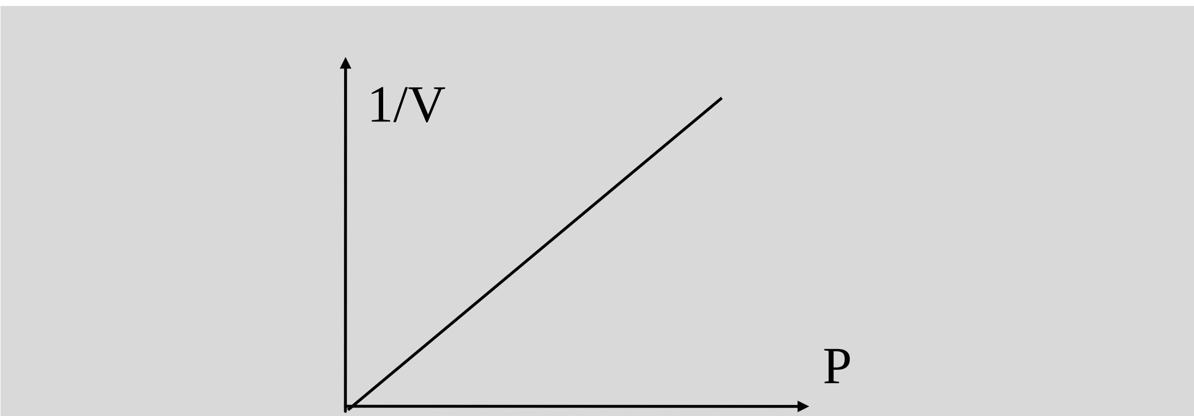
VOLUME measured in m^3

TEMPERATURE measured in degrees

Robert Boyle (1627-1691) investigated the variation of volume with pressure.

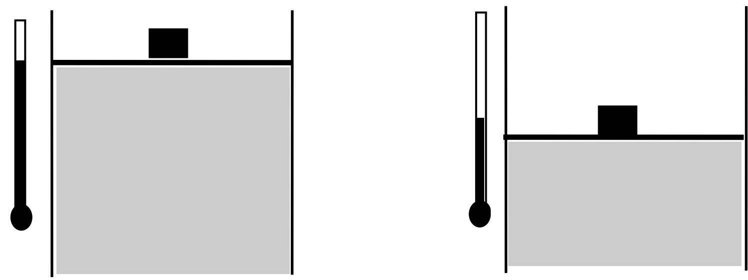


Squeeze a gas, it gets smaller.

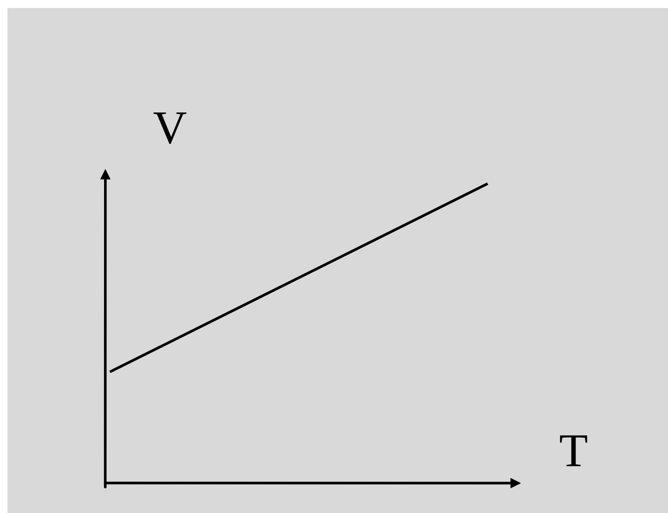


Boyle's Law: For a fixed mass of gas , at constant temperature, the pressure is inversely proportional to volume.

Jacques Charles (1747-1823) investigated the variation of volume with temperature.



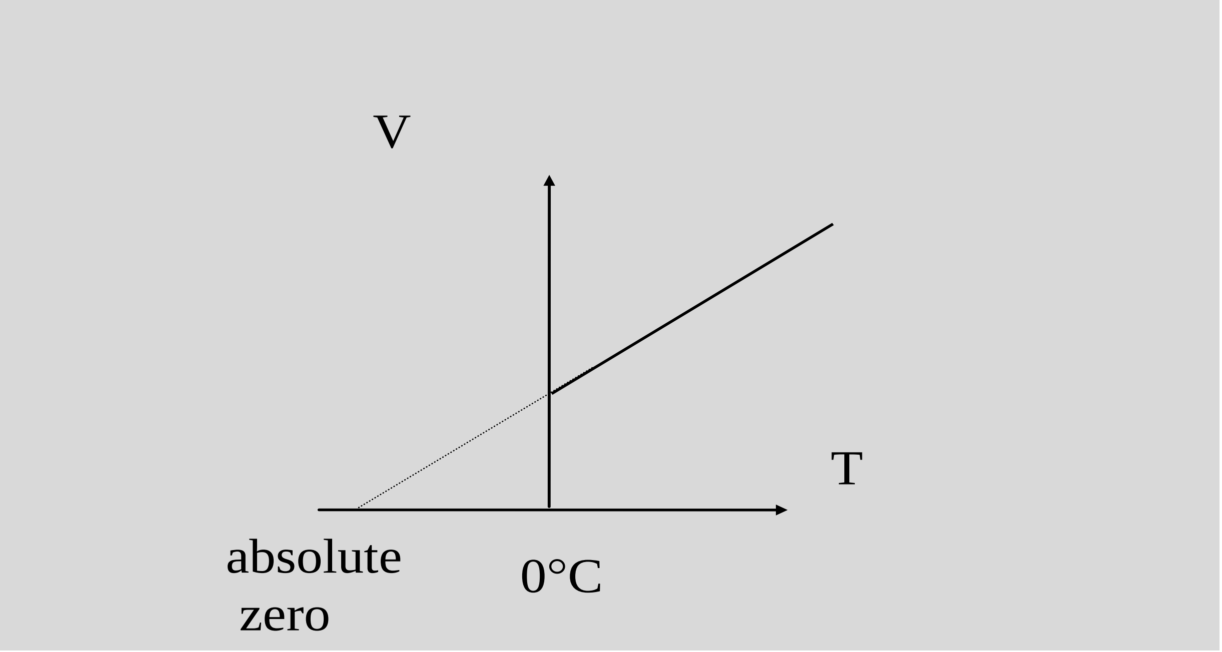
Cool a gas, and it contracts.



Charles's Law: For a fixed mass of gas, at constant pressure, the volume varies linearly with temperature.

Absolute zero

Although Charles's law does not give a proportionality between volume and temperature, this is only because of our arbitrary choice of the zero for the Celsius temperature scale.



By measuring temperature from a certain value, called the **absolute zero of temperature**, Charles's law gives a proportionality between volume and temperature.

Degrees Celsius from the absolute zero are called *kelvin* (K)
(after William Thomson, Lord Kelvin)

The absolute zero of temperature corresponds to approximately -273°C

Combining Boyle's and Charles's laws gives:

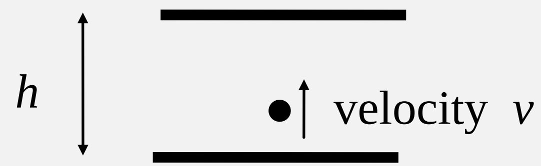
$$PV \propto T$$

The **kinetic theory of gases**, developed in the late 19th century by scientists such as Maxwell, Boltzmann and Clausius, obtains this equation as a consequence of classical mechanics - **Newton's laws**.

The assumptions made are:

- gas consists of a large number of particles that do not interact, except when they collide elastically
- these particles move with some average velocity and hence have an average kinetic energy

Deriving the gas laws from Newton's laws of motion



Suppose that a particle of mass *m* is bouncing between two plates with a velocity *v*.

Then the momentum change at each collision is *2mv*.

The particle takes *h/v* seconds to go from one plate to the other. Hence, it hits each plate once every *2h/v* seconds.

Thus, the rate of change of momentum is:

$$F = \frac{\Delta p}{\Delta t} = \frac{2mv}{2h/v} = \frac{mv^2}{h}$$

The pressure is the force per unit area:

$$P = \frac{F}{A} = \frac{mv^2}{Ah} = \frac{mv^2}{V}$$

$$PV = 2.KE$$

This is the pressure exerted by a single particle moving in one direction with the given KE. If we have a large number *n* of particles, with an a average kinetic energy <*KE*>, moving in 3 dimensions, then:

$$PV = \frac{2}{3} n.\langle KE \rangle$$

Thus, Boyle's law implies that the kinetic energy of a gas is related to temperature: at constant temperature, the kinetic energy is constant.

Furthermore, if $$PV \propto T$$

then $$\langle KE \rangle \propto T$$

In other words, kinetic theory establishes a direct link between temperature and the average kinetic energy of the particles of the gas.

Heat is just the kinetic energy of the *gas.*

- **In this model, the absolute zero of temperature is the temperature where the KE is zero.**

- **Since KE cannot be less than zero (½ mv^2), it is not possible to have a temperature less than absolute zero.**