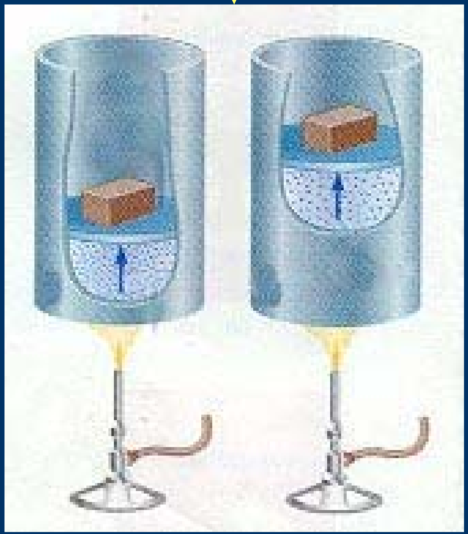
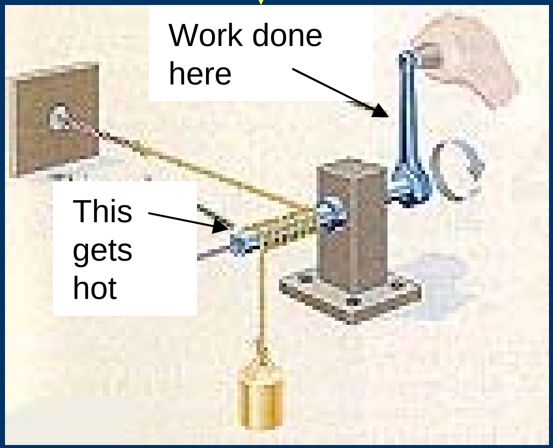
2.1, 2.2

Thermodynamics

"thermo": Greek *therme* heat
"dynamics": Greek *dynamikos* powerful

The study of the connection between heat and work and the conversion of one into the other.





change heat into work (such as an automobile engine) or turn work into heat (or cooling, as in a refrigerator).

pump in a refrigerator -- it expands the gas, causing it to become cold. This is converting mechanical energy into heat (cold) energy.

There are two laws of thermodynamics that explain the connection between work and heat.

Work

Mechanical work

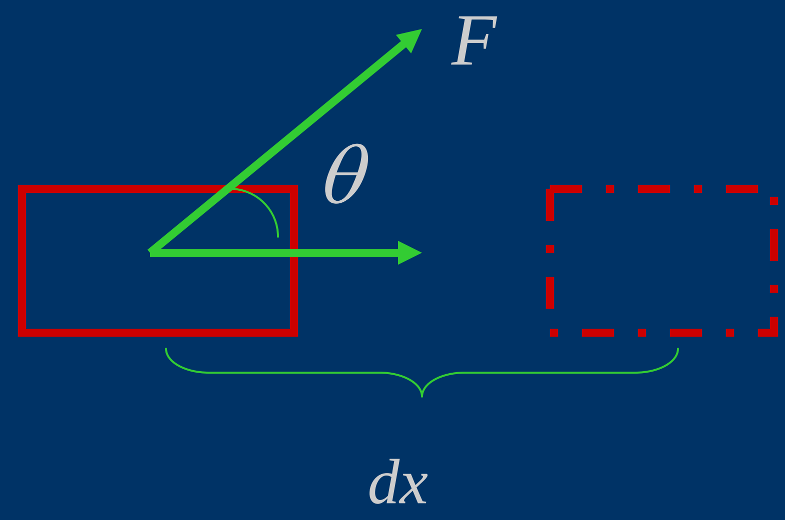
a force times the distance
through which it acts.
one dimensional motion

$$w = fx$$

Finite motion

$$dW = -F\cos\theta dx$$

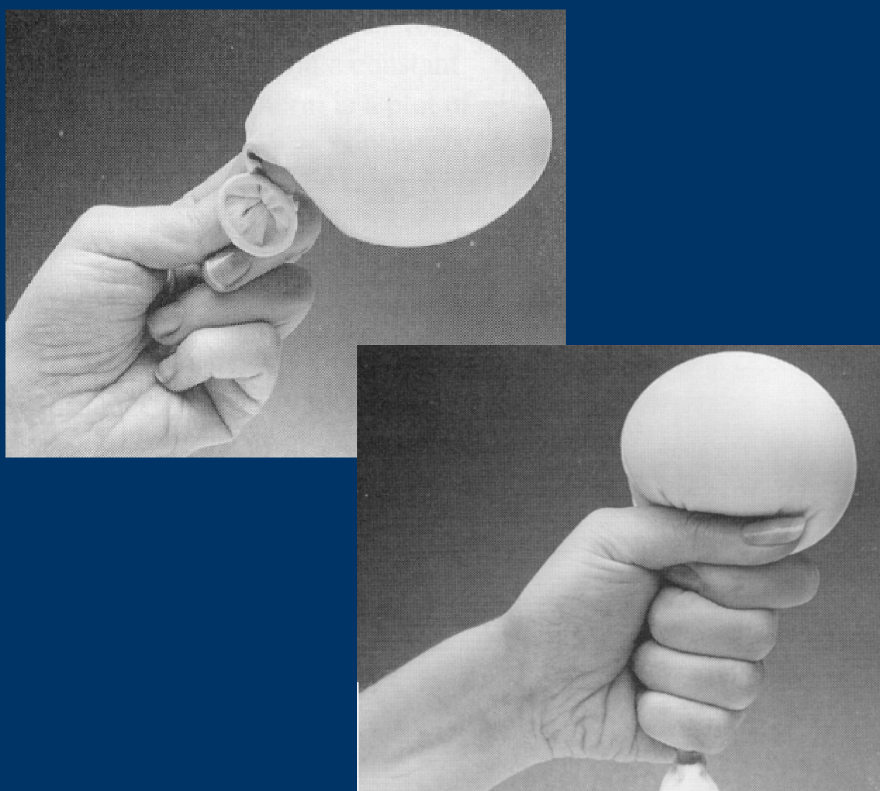
angle between the
displacement and
the applied force



Work is an algebraic quantity

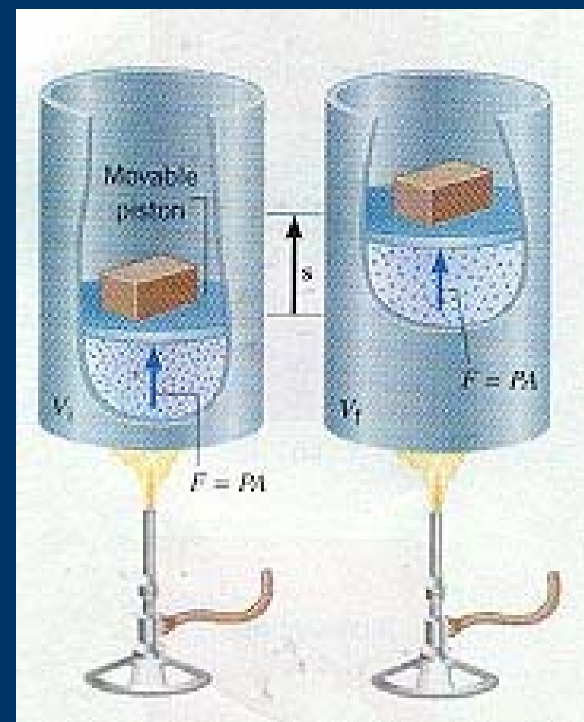
Positive

Work done **on** a system



Negative

Work done **by** a system

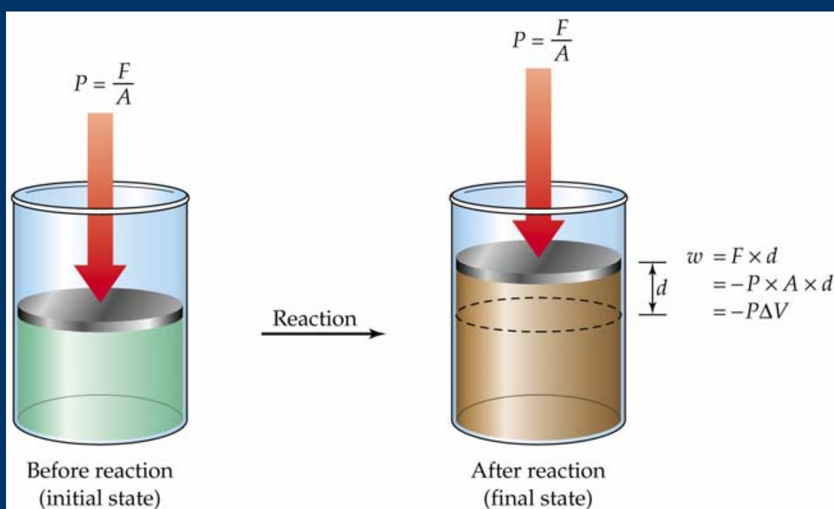


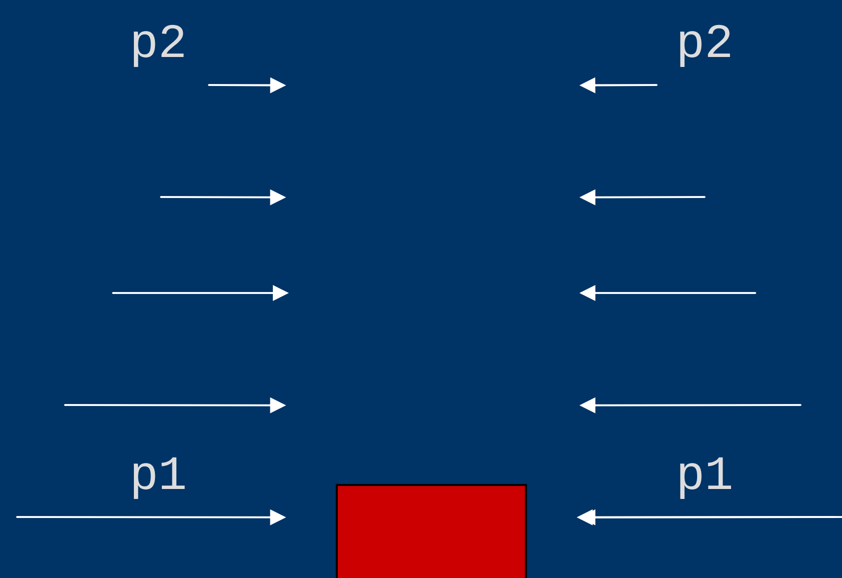
different kinds of work

Because of its importance in thermodynamics, we will focus on the work produced by varying the volume of a system

"expansion work" or "compression work"

Parcel rises





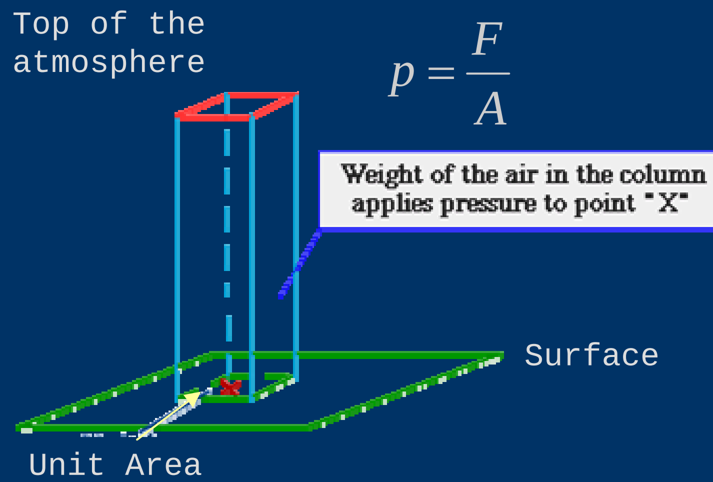
Expansion work

$$dW = -Fdx$$

$$dW = -pAdx$$

$$dW = -pdV$$

$$p = \frac{F}{A}$$



$$Adx = dV$$

Differential volume change associated with the work done

Specific work

Intensive variables

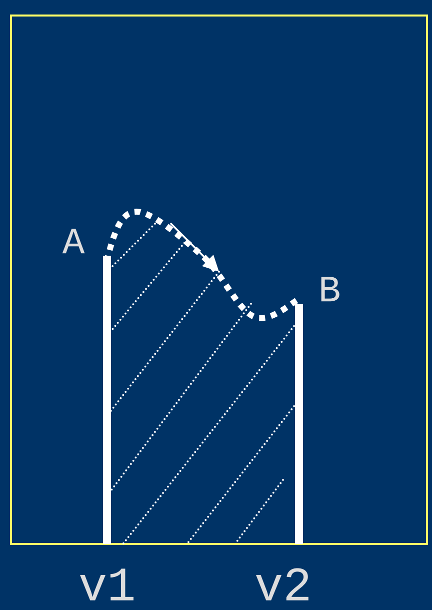
$$w = W / m$$

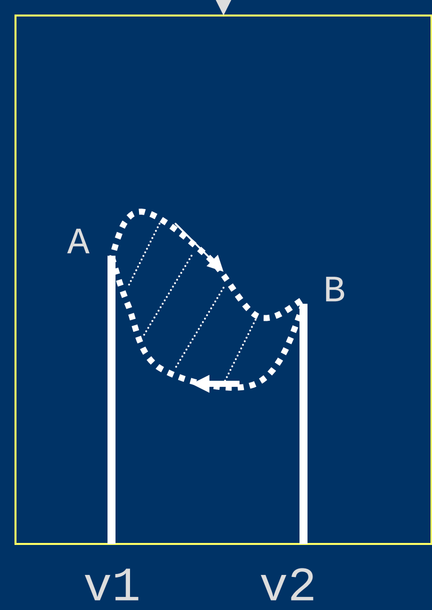
$$dw = -pdv$$

For a finite expansion or compression from v1 to v2:

$$w = -\int_{v_1}^{v_2} p\,dv$$

Cyclical processes have the same initial and final state





The work depends on the path, and is not necessarily zero

generally

$$\oint dw \neq 0$$

WORK IS NOT AN EXACT DIFFERENTIAL

Heat

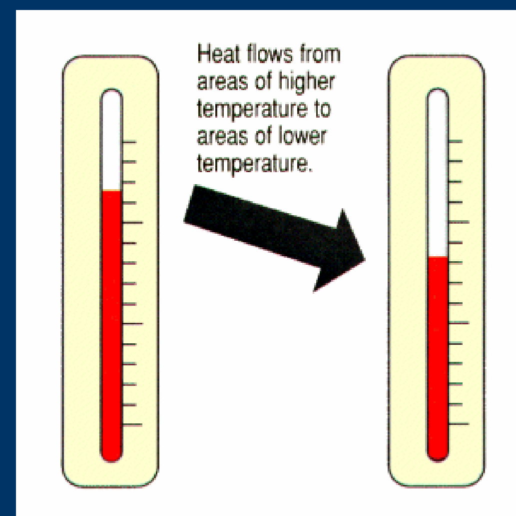
Heat is a quantity that flows across the boundary of the system during a change in state by virtue of a difference in temperature between the system and its surroundings.

algebraic quantity

positive when it flows **from the surrounds to the system** (same convention as for work).

T1 ⟷ T2

Final temperature T’



Heat transfer

$$c_2 m_2 (T' - T_2) + c_1 m_1 (T' - T_1) = 0$$

Specific heat capacity

Depends on physical state and chemical composition

The final equilibrium temperature

$$T' = \frac{c_2 m_2 T_2 + c_1 m_1 T_1}{c_2 m_2 + c_1 m_1}$$

The amount of heat lost by the warmer body is equal in magnitude to the amount of the heat gained by the cooler body

$$\Delta Q = c_1 m_1 (T_1 - T') = c_2 m_2 (T' - T_2)$$

Differential form

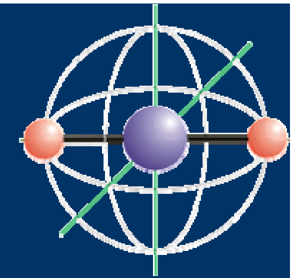
$$dQ = mcdT$$

$$\oint dQ \neq 0$$

HEAT IS NOT AN EXACT DIFFERENTIAL

Specific heat capacity

$$c = \frac{dq}{dT}$$



Specific heat of ideal gases

C_v C_p → for a ideal gases can be determined by consider their mechanical degrees of freedom

Average molecular kinetic energy of a gas →

$$\mathcal{E}_k = \frac{3}{2} nR*T$$

a mole of a <u>monoatomic</u> gas

3 degrees of freedom

In general, a N-atomic molecule has 3N DOF

$$\mathcal{E}_k = \frac{3}{2}(1)R*T \longrightarrow \mathcal{E}_k(\text{per dof}) = \frac{\frac{3}{2}(1)R*T}{3} = \frac{1}{2}R*T$$

Generalization for N-atomic molecules

theorem of equipartition of energy

The energy of each translational and rotational DOF is associated to

$$\left(1/2\right)R*T$$

And each vibrational DOF is associated to

$$\left(1/2\right)R*T+\left(1/2\right)R*T$$

$$R$$

(It has potential and kinetic energy components)

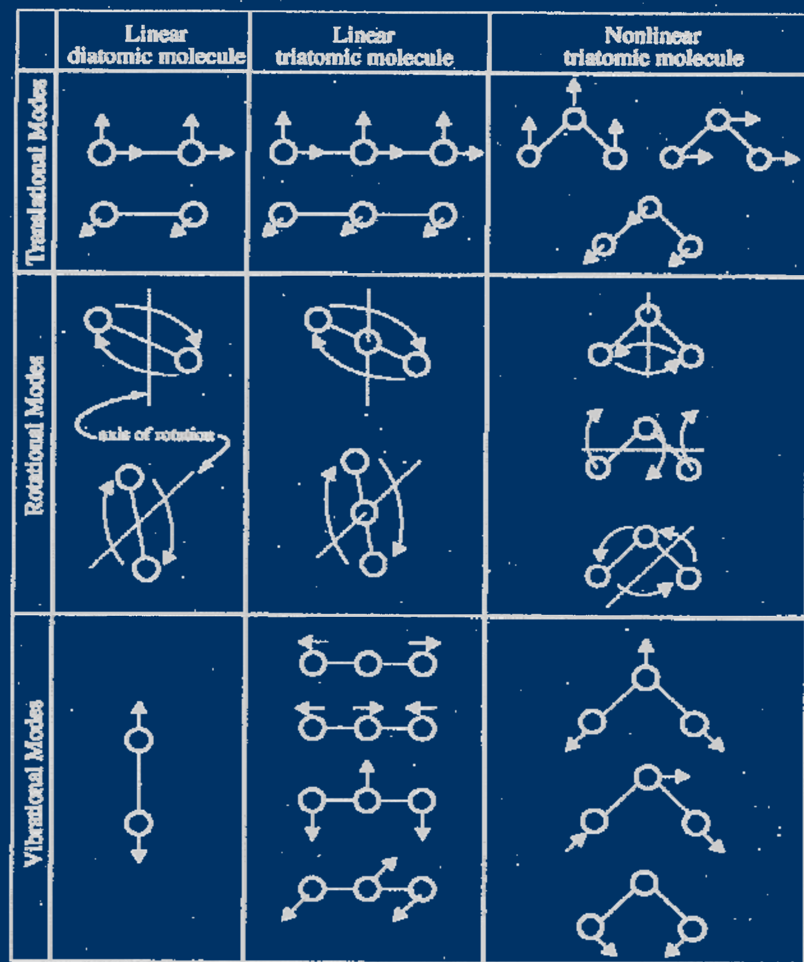


Figure 2.7 Illustration of molecular translational, rotational, and vibrational motions.

The heat capacity of an ideal gas can be determined as the sum of the contributions to the thermal energy of each mechanical degree of freedom

$$\left(1/2\right)R$$ Per each DOF

degrees of freedom	**Nonlinear Molecule**	**Linear Molecule**
Translation	3	3
Rotation	3	2
Vibration	3N-6	3N-5

For a diatomic gas → $c_v = 3\left(\frac{1}{2}R\right) + 2\left(\frac{1}{2}R\right) + 1(R) = \frac{7}{2}R$

earth → $\frac{5}{2}R$

We will show later

$$c_v - c_p = R$$