Quiz 8, MONDAY

November 2013

Su	Mo	Tu	We	Th	Fr	Sa
					1	2
3	4	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28	29	30

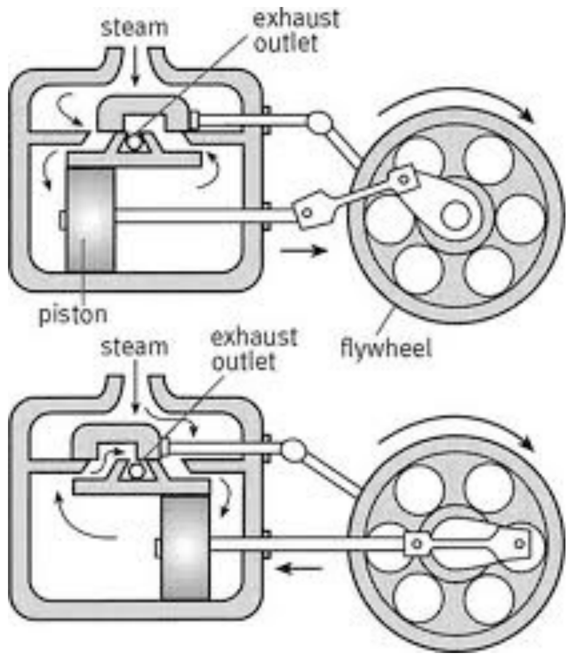
Please send me an email ASAP if you are away Monday, Nov. 25. You can take the quiz on Friday Nov 22, during your usual time. (You'll have to miss the Friday lecture).

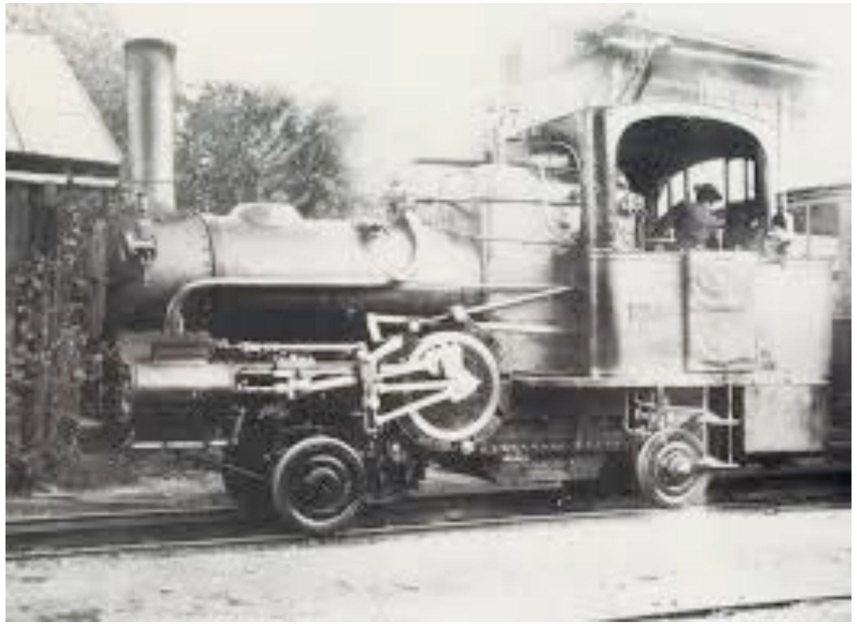
First Law of Thermo.

Ken Intriligator's week 5 lectures, Oct 21, 2013

Heat, work, and

Conservation of Energy





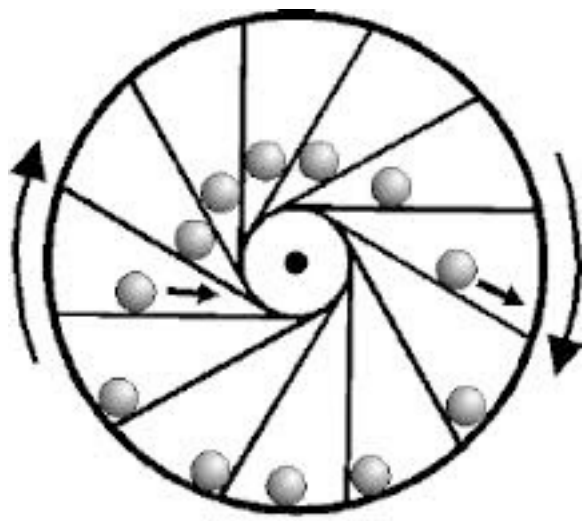
Energy is conserved

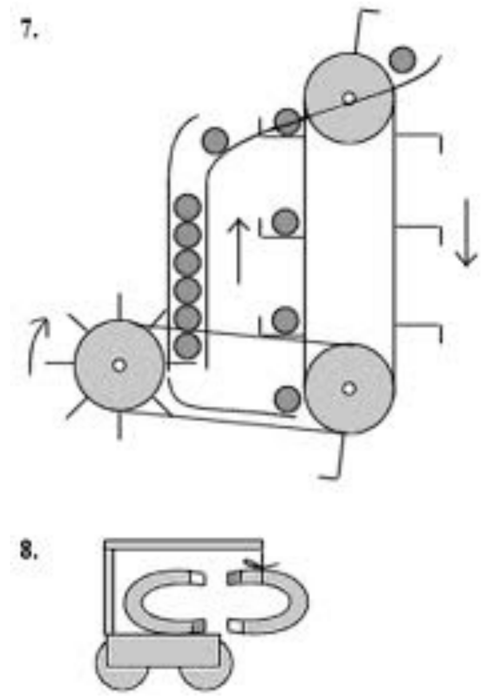
- It can not be created or destroyed, only moved around. Sometimes it is useful, and can do work. Other times it takes a useless form.
- Discovered / understood in the 1800s, in the context of trying to build better engines. Led to laws of thermodynamics.
- Conservation laws = fundamental and deep.

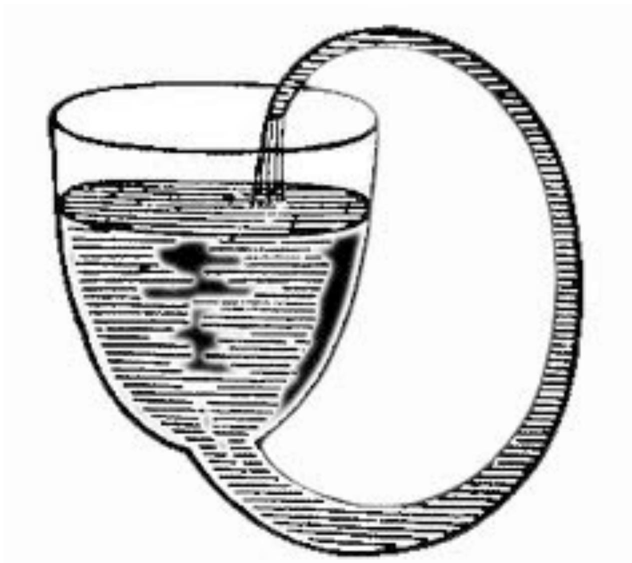
Aside: conservation

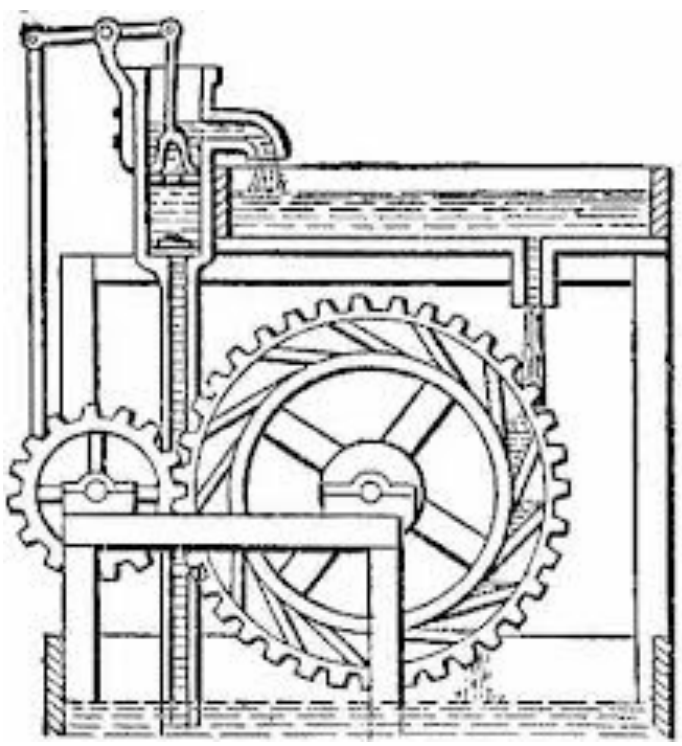
There is a deep connection between conservation laws and symmetries. Energy conservation is equivalent to invariance of Nature under time translations. Momentum conservation is equivalent to invariance of Nature under space translations. Angular momentum conservation is equivalent to invariance of Nature under rotations. All of these are fundamental and no violation has ever been observed. They are exact. Any violation of these conservation laws would be a huge surprise, and lead to many puzzles.

Perpetual motion? No!









Thousands of failed inventor’s attempts. Would violate thermodynamic laws. Thermodynamics works!

First law of Thermo

Let's first write the equations. We'll then explain them in detail, using the chalkboard.

$$\boxed{dE = đQ - đW}$$

$$\boxed{đW = pdV}$$

$dE =$ Change in a system's internal energy

$đQ =$ Change in a system's heat content.

$đW =$ Work done **by** the system.

Next week: $\boxed{đQ = TdS}$ S=entropy.

Why the $đ$?

Basic calculus: $$\int_{x_i}^{x_f} dF = \int_{x_i}^{x_f} \frac{dF}{dx} dx = F(x_f) - F(x_i)$$

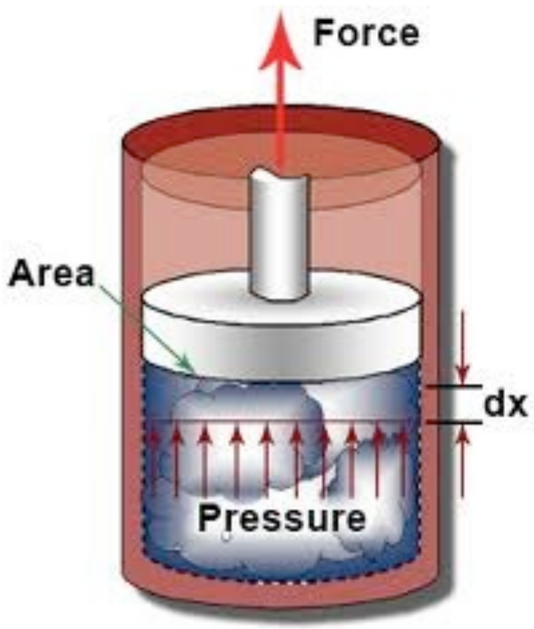
Depends only on endpoints.

On the other hand: $$\int_{path} đW \neq W|_f - W_i$$

Work done depends on the path, not just the endpoints.
The slash is there as a reminder. Note no slash for dE.

$$\boxed{dE = đQ - đW}$$

$$\text{đ}W = pdV$$



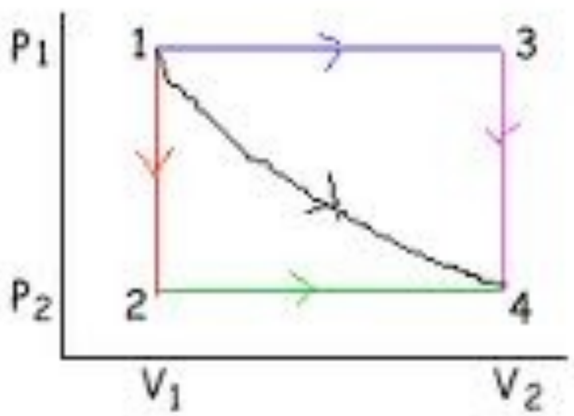
$$\text{đ}W = Fdx = pAdx = pdV$$

dV can be positive or negative.

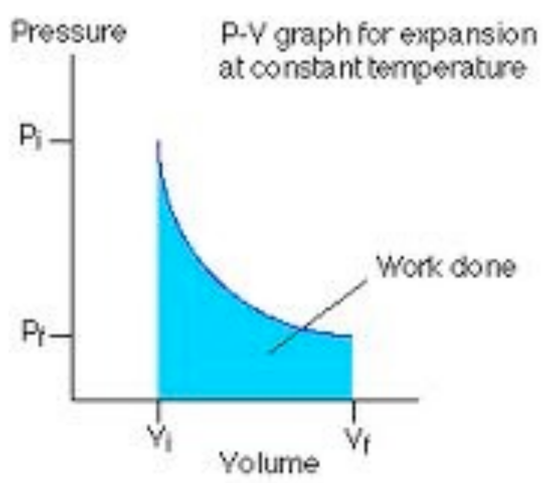
This is the work done **by** the gas in the piston. The internal energy of the gas is reduced by this amount if the work done is positive, i.e. if dV>0.

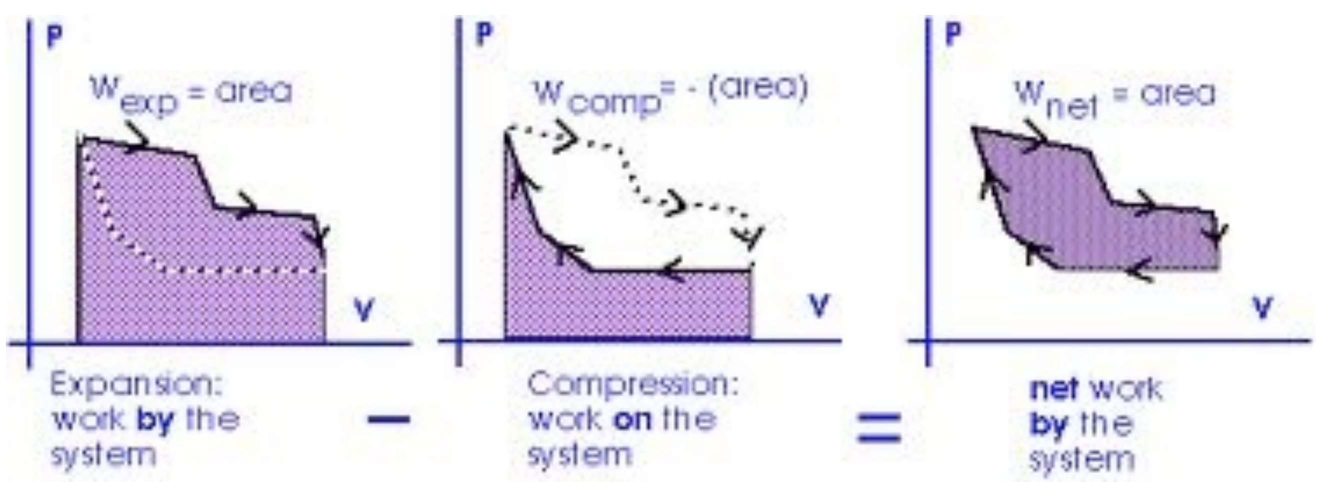
Work done by system

$$đW = pdV$$

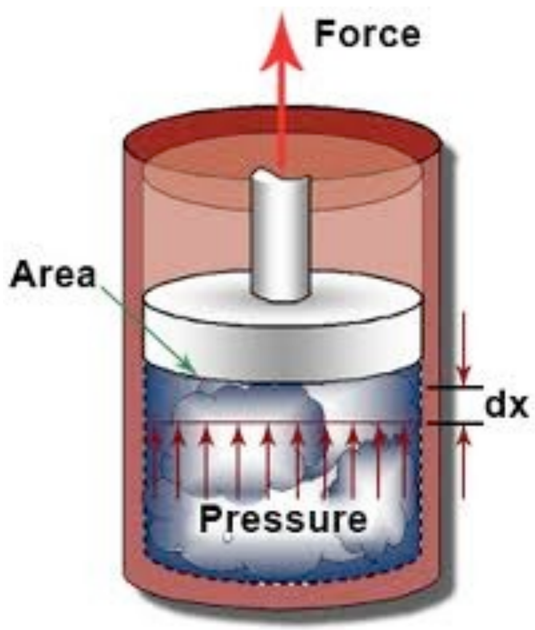


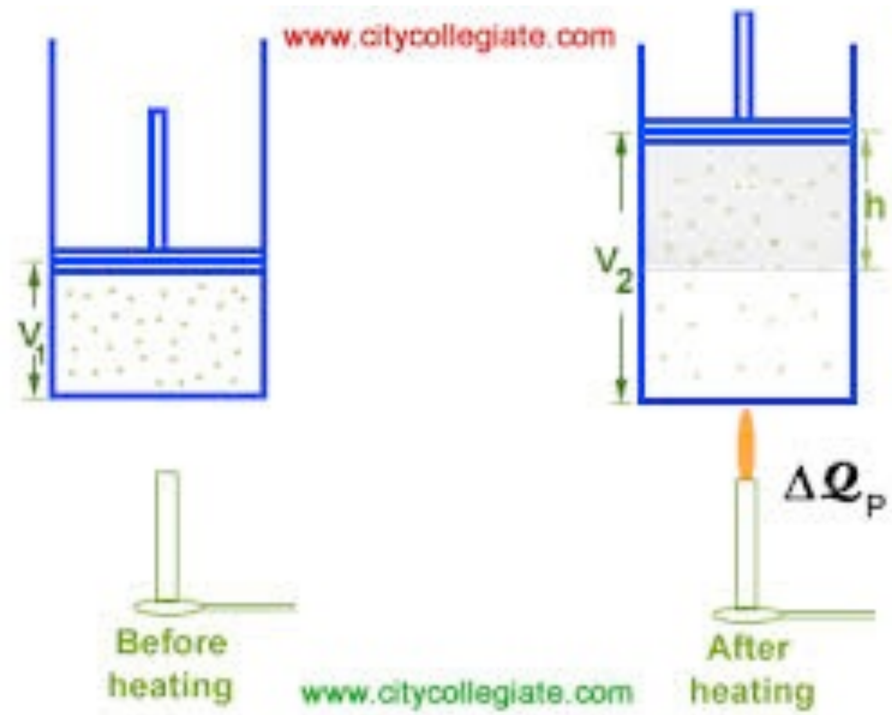
p,V diagrams. Work done
is the area under the curve.
Depends on path & orientation.





$$đQ$$ = Heat added to system.





$$\Delta Q = \int_{path} đQ$$

(Like work, depends on path, not just endpoints.)

First law (integrated)

$$\Delta E|_{endpoints} = \Delta Q|_{path} - \Delta W_{path}$$

$$E_f - E_i$$

$$\int_{path} \not{d}Q$$

$$\int_{path} pdV$$

Process Terminology

- Cyclic: system brought back to initial state at the end. Then $\Delta E = 0$
- Adiabatic: $\not{d}Q = \Delta Q = 0$
- Isochoric, Isobaric, Isothermal: fancy names for constant V, p, and T, respectively. We'll avoid using these fancy "Iso..." names.

Equipartition of E

(Average) energy of a gas is:

$$\boxed{E = \frac{1}{2} f N k_B T}$$

f = Integer, number of degrees of freedom.

Kinetic energy gives 3, rotational energy gives 2 or 3, depending on if it's diatomic or polyatomic. Vibrational energy can also contribute to f.

Monatomic: f=3.

Diatomic or polyatomic: f=3,5, 7 depending on T.

Heat capacities

C_V at constant volume; C_P at constant pressure.

C_V case: no work. So $dE = \frac{1}{2} f N k_B dT = dQ$

$C_V = \frac{dQ}{dT}|_V = \boxed{\frac{1}{2} f N k_B} = \frac{1}{2} f n R$, so $c_V = C_V/M = f k_B/2m$

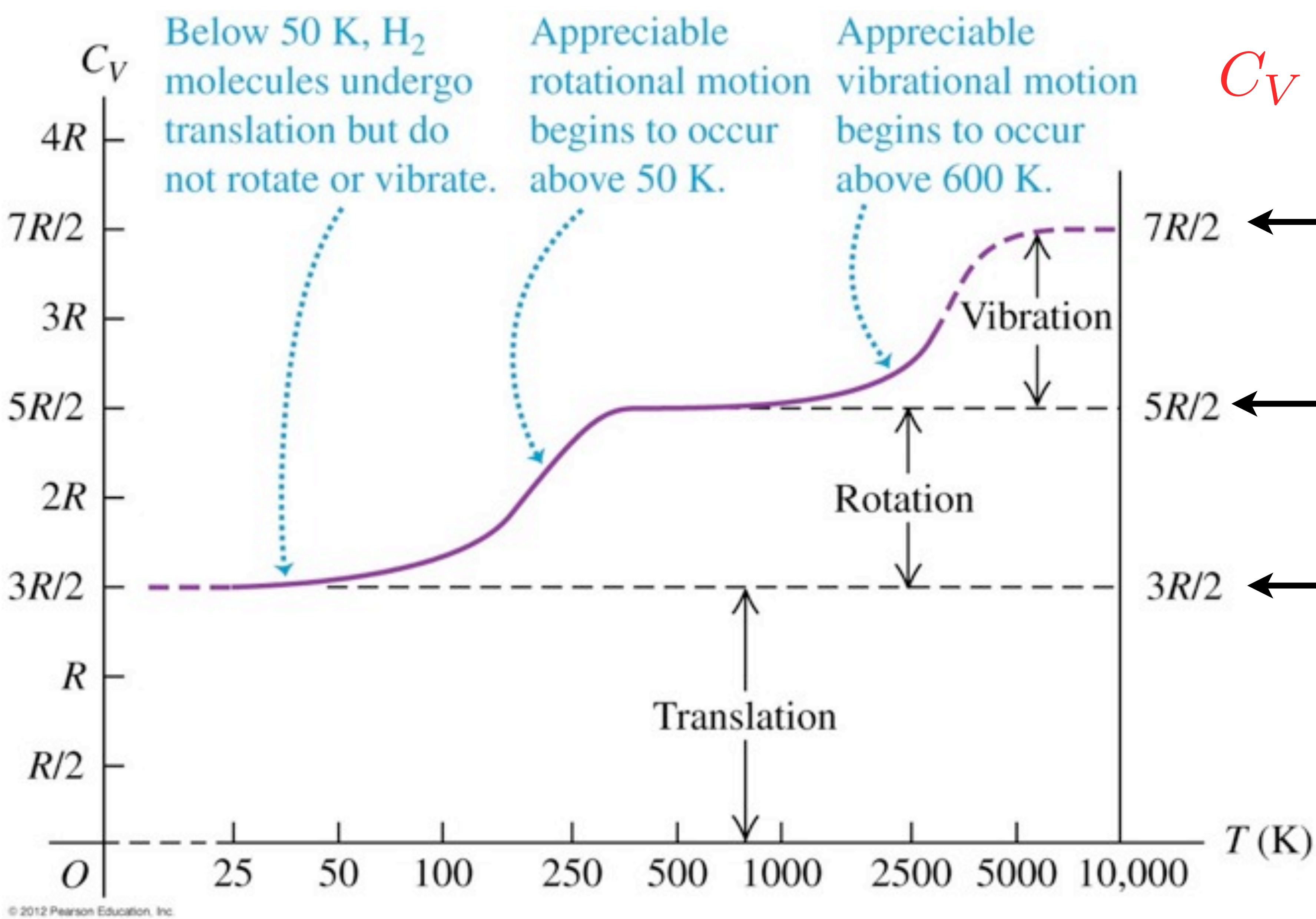
C_P case: $pdV = d(pV) = N k_B dT$

$$dE = \frac{1}{2} f N k_B dT = dQ|_p - N k_B dT$$

$C_p = \frac{dQ}{dT}|p = \boxed{N(\frac{1}{2} f + 1) k_B}$, so $c_p = C_p/M = (\frac{1}{2} f + 1) k_B/m$

Historical Hint of QM:

Puzzle, known to Maxwell in 1860:



$$C_V = \frac{1}{2} f n R$$

$f = 7$

$f = 5$

$f = 3$

Adiabatic process

$$dQ = \frac{1}{2} N f k_B dT + pdV = 0$$

& $$N k_B dT = d(pV) = pdV + Vdp$$

so $$(\frac{1}{2} f + 1) pdV + \frac{1}{2} f V dp = 0$$

$$\gamma \; dV/V = -dp/p$$

$$\gamma \equiv (\frac{1}{2} f + 1) / \frac{1}{2} f$$

$$\boxed{pV^{\gamma} = constant}$$

$$\boxed{\gamma \; \equiv 1 + (2/f)}$$

$$\boxed{\gamma = C_p / C_V}$$

Isothermal process

$$dE = \frac{1}{2} f N k_B dT = 0$$

$$d(pV) = N k_B dT = 0$$

$$pV = const.$$

$$\Delta W = \int_{V_i}^{V_f} p dV = \int_{V_i}^{V_f} N k_B T \frac{dV}{V} = N k_B T \ln(V_f / V_i)$$

Makes sense.

Adiabatic process

$$\Delta W = -\Delta E = \frac{1}{2} f N k_B (T_i - T_f)$$

$$= \frac{1}{2} f (p_i V_i - p_f V_f) = \frac{1}{\gamma - 1} (p_i V_i - p_f V_f)$$

Speed of sound in gas

Recall $v_{sound} = \sqrt{B/\rho}$

$$B = -dp/(dV/V)$$

adiabatic $d(pV^{\gamma}) = 0 \longrightarrow dp + \gamma p dV/V = 0$

$$\longrightarrow B = \gamma p$$

$$v_{sound} = \sqrt{\frac{\gamma p}{\rho}} = \sqrt{\frac{\gamma p V}{M}} = \sqrt{\frac{\gamma N k T}{m N}} \longrightarrow v_{sound} = \sqrt{\frac{\gamma k T}{m}}$$

Recall $v_{RMS} = \sqrt{\frac{3kT}{m}}$

$v_{sound} < v_{RMS}$

makes sense..

Now, chalkboard.

- The material now is better explained and illustrated on the chalkboard.