The first law of thermodynamics

$$\boxed{\Delta U = Q - W}$$

The change ~~increase~~ in internal energy of a closed system is equal to the difference of the heat supplied to the system and the work done by it.

CONSERVATION OF ENERGY

piston $F = pA$

work in x-direction $dW = F dx = pA dx$

$$A dx = dV$$

So, $dW = p dV$

$$W = \int_{V_1}^{V_2} p \, dV$$ work done in a volume change

must know $p(V)$
or $p$ is constant

# EXAMPLE 1

An ideal gas undergoes an isothermal expansion at temperature $T$, its volume changes from $V_1$ to $V_2$. How much work does the gas do?

$$pV = nRT$$

$$W = \int_{V_1}^{V_2} p\,dV$$

$$W = \int_{V_1}^{V_2} \frac{nRT}{V}\,dV$$

$$= nRT \int_{V_1}^{V_2} \frac{dV}{V}$$

$$\boxed{W = nRT \ln\left(\frac{V_2}{V_1}\right)}$$

ideal gas, isothermal process

$$p_1 V_1 = p_2 V_2$$

$$\text{or} \quad \frac{V_2}{V_1} = \frac{p_1}{p_2}$$

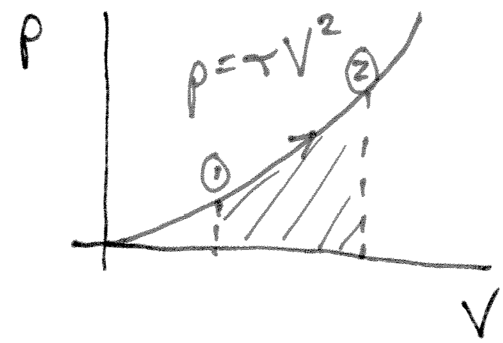
$$\boxed{W = nRT \ln\left(\frac{p_1}{p_2}\right)}$$

I.G., isothermal process

# EXAMPLE 2



An ideal gas is taken through a quasi-static process described by $P = \alpha V^2$, with $\alpha = 5.00$ atm/m$^6$. The gas is expanded to twice its initial volume of 1.00 m$^3$. How much work is done on the expanding gas in the process?




$$W = -\int_{V_1}^{V_2} P\,dV$$

$$= -\int_{V_1}^{V_2} \alpha V^2\,dV$$

$$= -\frac{1}{3}\alpha\left(V_2^3 - V_1^3\right)$$

$$= -\frac{1}{3}\left(5.00\ \text{atm/m}^6\right)\left(1.013\times10^5\ \frac{\text{Pa}}{\text{atm}}\right)\left[\left(2.00\,\text{m}^3\right)^3 - \left(1.00\,\text{m}^3\right)^3\right]$$

$$= -1.18\times10^6\ \text{J}$$

EXAMPLE 3

A thermodynamic system undergoes a process in which its internal energy decreases by 500 J. Over the same time interval, 220 J of work is done on the system. Find the energy transferred from it by heat.

$$\Delta U = Q - W$$

$$-500\text{ J} = Q - (-220\text{ J})$$

$$Q = -500\text{ J} - 220\text{ J}$$

$$= -720\text{ J}$$

# EXAMPLE 4

A student eats a Tim Horton's breakfast (620 Calories). They wish to do an equivalent amount of work in the gym by lifting a 5.0 kg barbell. How many times must the barbell be raised to expend this much energy? Assume the barbell is raised 1.00 m for each lift and no energy is expelled when lowering barbell.

cyclic process

$$\Delta U = 0$$

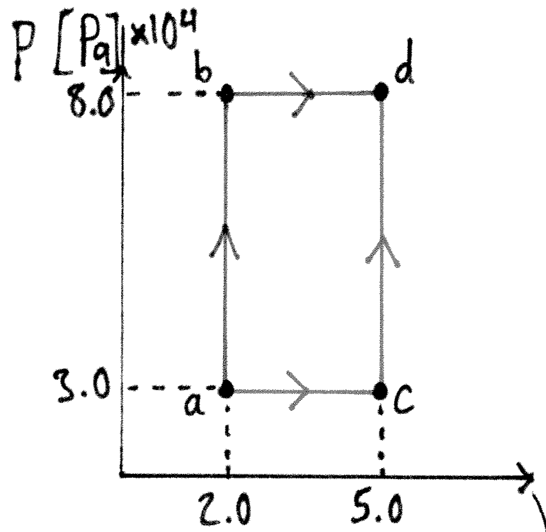
$$Q = W$$

$$Q = (620 \text{ Calories})(1\times10^3 \text{ cal/Calories})(4.186 \text{ J/cal})$$
$$= 2.6\times10^6 \text{ J}$$

$$W = mgh \times n$$
$$= (5.0 \text{ kg})(9.8 \text{ m/s}^2)(1.00 \text{ m})n$$
$$= (49 \text{ J})n$$

$$n = \frac{2.6\times10^6}{49} = \underline{53000} \text{ lifts!}$$

# EXAMPLE 5




The pV diagram shows a series of thermodynamic processes. In process ab, 150 J of heat is added to the system; in process bd, 600 J of heat is added. Find

a) internal energy change in process ab

b) internal energy change in process abd

c) the total heat added in process acd

$$\Delta U = Q - W$$

given $Q_{ab} = 150\ J$, $Q_{bd} = 600\ J$ } +'ve, heat added

a) $W_{ab} = 0 \Rightarrow \Delta U_{ab} = Q_{ab} - 0 = 150\ J$

b) $\Delta U_{abd} = \Delta U_{ab} + \Delta U_{bd}$

$= 150\ J + (Q_{bd} - W_{bd})$

$= 150\ J + 600\ J - W_{bd}$

$W_{bd} = p\Delta V$

$= (8.0 \times 10^4\ Pa)(5.0 - 2.0) \times 10^{-3}\ m^3$

$= 240\ J$

$$\Delta U_{abd} = 510\ J$$

c) $\Delta U_{acd} = Q_{acd} - W_{acd}$

$\Delta U$ is independent of path

$\Delta U_{acd} = \Delta U_{abd} = 510\ J$

want $Q_{acd}$, need $W_{acd}$

$$W_{acd} = W_{ac} + W_{cd}$$
$$= p(V_2 - V_a) + 0$$
$$= (3 \times 10^4\ Pa)(5 \times 10^{-3}\ m^3 - 2 \times 10^{-3}\ m^3)$$
$$= 90\ J$$

$$Q_{acd} = \Delta U_{acd} + W_{acd}$$
$$= 510\ J + 90\ J$$
$$= \underline{600\ J}$$