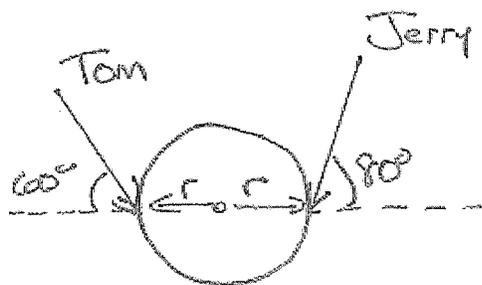


Physics 151

HW#7

#1

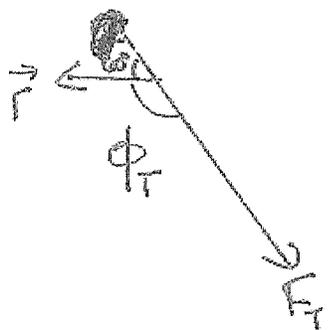


diameter of 3m  $\Rightarrow r = 1.5\text{m}$

a) Tom pushes with  $F_T = 40\text{N}$ , Jerry with  $F_J = 35.2\text{N}$

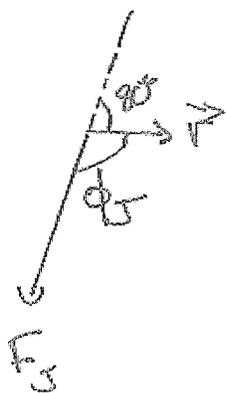
What is Net Torque? BOTH Tom & Jerry Pushing at  $r = 1.5\text{m}$

$$\Rightarrow \tau_T = F_T r \sin \phi_T, \quad \tau_J = F_J r \sin \phi_J$$



$$\phi_T = 180^\circ - 60^\circ = 120^\circ$$

$$\tau_T = (40\text{N})(1.5\text{m}) \sin 120^\circ = 51.96\text{N}\cdot\text{m} \\ \approx 52\text{N}\cdot\text{m}$$



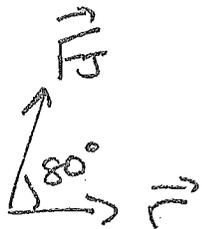
$$\phi_J = 180^\circ - 80^\circ = 100^\circ$$

$$\tau_J = (35.2\text{N})(1.5\text{m}) \sin 100^\circ = 51.998\text{N}\cdot\text{m} \\ \approx 52\text{N}\cdot\text{m}$$

Tom's torque trying to make wheel spin Counter-clockwise  
While Jerry's is trying to make wheel spin clockwise

$$\Rightarrow \tau_{\text{net}} = \tau_T - \tau_J = 0$$

b) what if Jerry Reverses his force



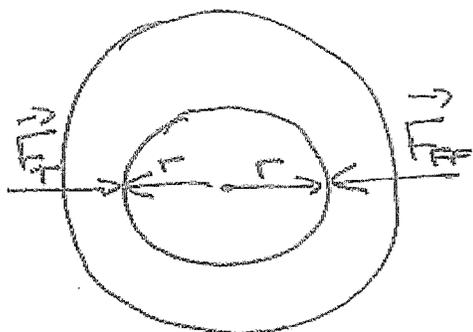
$$\tau_J = (35.20)(1.5\text{m})\sin 80^\circ = 51.998\text{N}\cdot\text{m} = 52\text{N}\cdot\text{m}$$

$\Rightarrow$  SAME MAGNITUDE but now his force

Also tries to spin counter-clockwise

$$\Rightarrow \tau_{\text{net}} = \tau_T + \tau_J = 52\text{N}\cdot\text{m} + 52\text{N}\cdot\text{m} = 104\text{N}\cdot\text{m}$$

#2



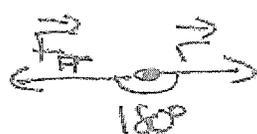
$$r = \frac{1\text{cm}}{2} = .5\text{cm} \times \frac{1\text{m}}{100\text{cm}} = .005\text{m}$$

$$\vec{F}_T = \text{THUMB FORCE}, F_T = 0.6\text{N}$$

$$\vec{F}_{FF} = \text{Forefinger}, F_{FF} = 0.6\text{N}$$

Both Fingers exert a force BUT NOT A TORQUE!

FOR BOTH



$$\sin 180^\circ = 0$$

IT'S FRICTION THAT EXERTS TORQUE. WITHOUT FRICTION your forefinger would slide upward (AND THEN COUNTERCLOCKWISE)

⇒ Frictional force on finger is DOWN. But we

want force on the lock. By 3<sup>RD</sup> LAW, there must be AN UPWARDS force on lock.

Let  $f_{FF\text{ on lock}}$  = friction from forefinger on lock.

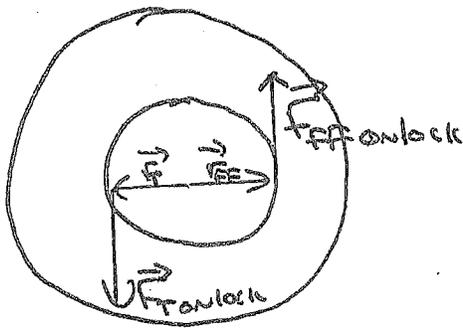
$$\text{at max } f_{FF\text{ on lock}} = \mu_s F_{FF} = 0.12(0.6\text{N}) = 0.072\text{N}$$

Amount of contact ⇒ Normal force.

By A similar Argument, force on lock from THUMB must be down

$$\rightarrow F_{T \text{ on lock}} = \mu_s F_T = 0.12(0.6\text{N}) = 0.072\text{N}$$

MAX



frictional  
Both of these <sup>^</sup> forces are  $90^\circ$  to their  $\vec{r}$

$$\Rightarrow \tau_{FF} = r_{FF} F_{FF \text{ on lock}}$$

$$= (0.005\text{m})(0.072\text{N}) = 0.00036\text{N}\cdot\text{m}$$

$$\tau_T = r_T F_{T \text{ on lock}} = (0.005\text{m})(0.072\text{N}) = 0.00036\text{N}\cdot\text{m}$$

BOTH TRYING to rotate lock Counter-clockwise  $\Rightarrow$

$$\tau_{\text{net}} = \tau_{FF} + \tau_T = 0.00036\text{N}\cdot\text{m} + 0.00036\text{N}\cdot\text{m}$$

$$\Rightarrow \tau_{\text{net}} = 0.00072\text{N}\cdot\text{m} = 7.2 \times 10^{-4}\text{N}\cdot\text{m}$$

#3

a.) Earth is APPROX. a solid sphere

$$M = 5.97 \times 10^{24} \text{ kg}, R = 6.38 \times 10^6 \text{ m}$$

$$I = \frac{2}{5} MR^2 \text{ for solid sphere}$$

$$\Rightarrow I = \frac{2}{5} (5.97 \times 10^{24} \text{ kg}) (6.38 \times 10^6 \text{ m})^2 = \underline{\underline{9.72 \times 10^{37} \text{ kg} \cdot \text{m}^2}}$$

b) The moment of inertia is actually smaller because its density isn't uniform. More mass near center gives an overall small moment since  $I = \sum_i M_i r_i^2$

c)  $K = \frac{1}{2} I \omega^2$  for spinning motion.

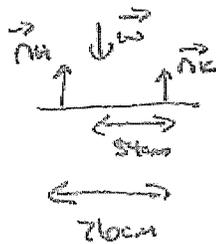
$$\text{Earth revolves once per day} \Rightarrow \omega = \frac{1 \text{ rev}}{24 \text{ h}} \times \frac{2\pi \text{ rad}}{1 \text{ rev}} \times \frac{1}{3600 \text{ s}} = 7.27 \times 10^{-5} \text{ rad/s}$$

$$\Rightarrow K = \frac{1}{2} (9.72 \times 10^{37} \text{ kg} \cdot \text{m}^2) (7.27 \times 10^{-5} \text{ rad/s})^2 = \underline{\underline{2.57 \times 10^{20} \text{ J}}}$$

↑  
insignificant

or that's a lot of Joules!

#4

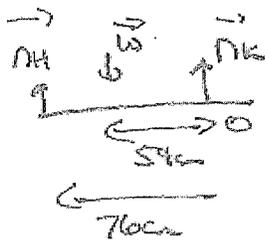


$\vec{N}_H$  = NORMAL force on HANDS

$\vec{N}_K$  = NORMAL force on KNEES

$$\omega = 580 \text{ N}$$

Let O be at KNEES



$\tau_K = 0$  since at O

$\vec{\omega}$  trying to do counter-clockwise while  $\vec{N}_H$  trying to do clockwise

$$\Rightarrow \tau_{\text{net}} = \tau_{\omega} - \tau_H. \quad \tau_{\text{net}} = 0 \Rightarrow \tau_{\omega} - \tau_H = 0$$

$$\Rightarrow \tau_{\omega} = \tau_H$$

both vertical forces  $\Rightarrow \tau_{\omega} = (54\text{cm})\omega, \quad \tau_H = (76\text{cm})N_H$

$$\Rightarrow (54\text{cm})(580) = (76\text{cm})N_H \Rightarrow N_H = \frac{(54\text{cm})(580)}{76\text{cm}} = 412.1 \text{ N}$$

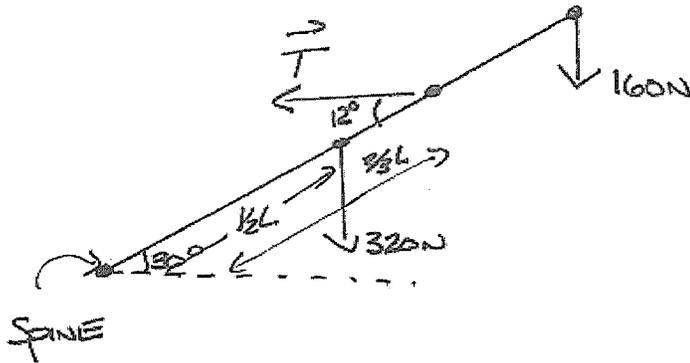
TWO HANDS!  $\Rightarrow$  ON EACH HAND  $N = \frac{N_H}{2} = \frac{412.1 \text{ N}}{2} = 206 \text{ N}$

b)

$$\sum \vec{F}_y = 0 \Rightarrow N_H - \omega + N_K = 0 \Rightarrow 412.1 \text{ N} - 580 \text{ N} + N_K = 0$$

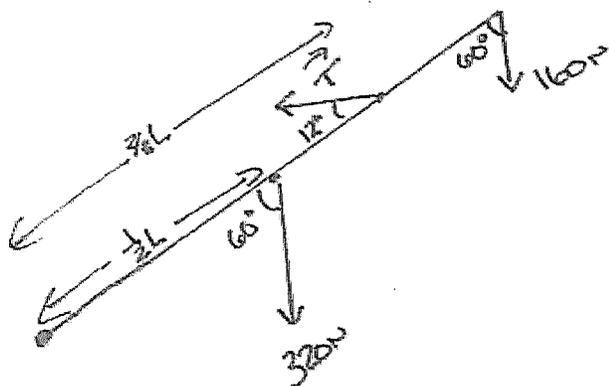
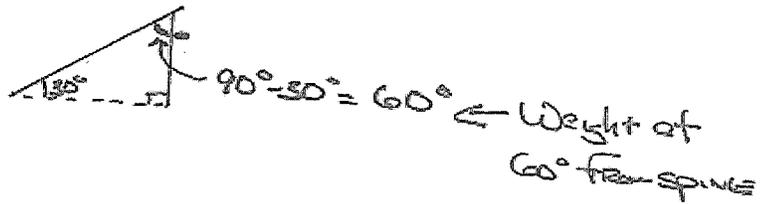
$$\Rightarrow N_K = 167.9 \text{ N.} \quad \text{TWO KNEES!} \Rightarrow \text{ON EACH KNEE } N = \frac{N_K}{2} = \frac{167.9 \text{ N}}{2} = 83.95 \text{ N} = 84 \text{ N}$$

#5



a) WHAT IS TENSION IN ERECTOR MUSCLE?

FIRST A LITTLE GEOMETRY:



$$\sum \tau = 0$$

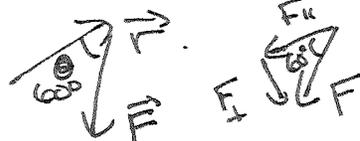
$$\Rightarrow -\tau_{320} + \tau_T - \tau_{1600} = 0$$

Due to 320N.  
Clockwise  $\Rightarrow$  Negative

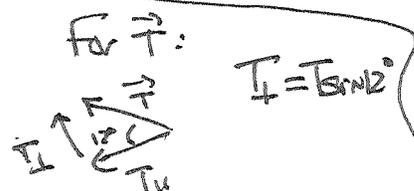
Due to Tension  
Counter-clockwise  $\Rightarrow$  Positive

Due to 160N  
Also Clockwise

FOR EACH weight:



$$F_{\perp} = F \sin 60^{\circ}$$



$$T_{\perp} = T \sin 12^{\circ}$$

$$\therefore -\left(\frac{1}{2}L\right)(320N \sin 60^\circ) + \left(\frac{2}{3}L\right)(T \sin 12^\circ) - (L)(160N \sin 60^\circ) = 0$$

$$\Rightarrow -\left(\frac{1}{2}L\right)(277.1N) + \left(\frac{2}{3}L\right)(T)(.208) - L(138.6N) = 0$$

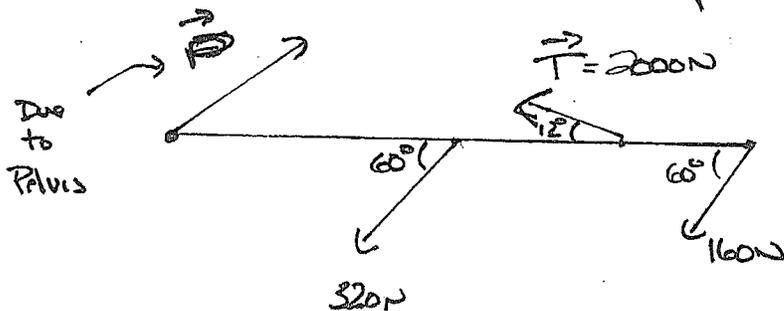
$$\Rightarrow -L(138.55N) + (.1387)L(T) - L(138.6N) = 0$$

L IN EACH TERM CANCELS ← WHY THEY DIDN'T GIVE YOU THE VALUE,

$$\Rightarrow -138.55N + .1387T - 138.6N = 0$$

$$\Rightarrow .1387T - 277.15N = 0 \Rightarrow T = 1998.2N \approx 2000N$$

Find  
b) FORCE DUE TO PELVIS'S COMPONENT ALONG SPINE.



$$\sum F_x = 0$$

y-Components =  $F_L \Rightarrow \sin$   
therefore x-Components =  $\cos$

All 3 KNOWN FORCES HAVE x-Components to LEFT

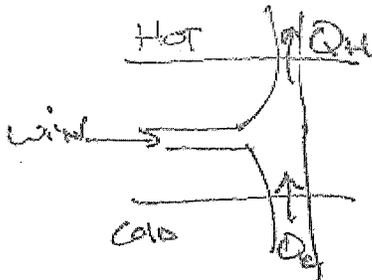
$$\Rightarrow R_x - 320N \cos 60^\circ - 2000N \cos 12^\circ - 160N \cos 60^\circ = 0 \quad \text{ouch!}$$

$$\Rightarrow R_x - 2196.3N = 0 \Rightarrow R_x = 2196.3N \approx 2200N$$

#6

250 students using 125 watt

AIR CONDITIONER with COP = 5. What minimum power



AIR CONDITIONER HAS TO REMOVE  
HEAT PRODUCED BY STUDENTS

$$\Rightarrow Q_c = Q_{\text{students}}$$

$W_{\text{in}}$  = Work done by electricity = ?

$$\text{For } \Delta t = 1\text{s}, \quad Q_c = 250 \text{ (125 watt)} (1\text{s}) = 31250\text{J}$$

↑                      ↑  
# of                      J/s  
student

$$\text{COP} = \frac{Q_c}{W_{\text{in}}} \Rightarrow W_{\text{in}} = \frac{Q_c}{\text{COP}} = \frac{31250\text{J}}{5} = 6250\text{J}$$

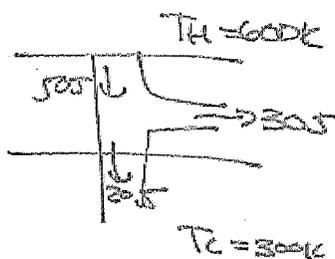
$$\text{So } P = \frac{W_{\text{in}}}{\Delta t} = \frac{6250\text{J}}{1\text{s}} = 6250\text{Watt}$$

#7

Engines

Which heat ~~engine~~ violate First Law or 2<sup>nd</sup> Law?

a)



$$W_{out} = 30\text{J}, Q_H = 50\text{J}, Q_C = 20\text{J}$$

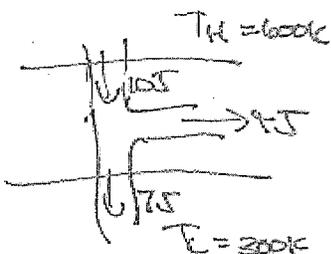
$$\text{First Law: } W_{out} + Q_C = Q_H$$

$$\Rightarrow 30\text{J} + 20\text{J} = 50\text{J} \checkmark \text{ First Law OK}$$

$$2^{\text{nd}} \text{ Law: } e_{max} = 1 - \frac{T_C}{T_H} = 1 - \frac{300\text{K}}{600\text{K}} = 1 - \frac{1}{2} = \frac{1}{2} = 0.5$$

$$\text{Here since } e = \frac{W_{out}}{Q_H} = \frac{30}{50} = 0.6 \leftarrow \text{Violates } 2^{\text{nd}} \text{ Law.}$$

b)

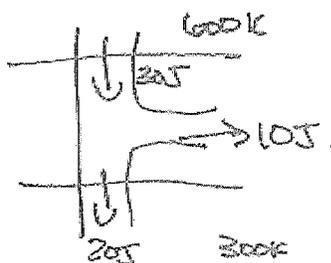


$$Q_H = 10\text{J}, Q_C = 7\text{J}, W_{out} = 4\text{J}$$

This violates First Law since

$$Q_C + W_{out} = 7\text{J} + 4\text{J} = 11\text{J} \neq Q_H = 10\text{J}$$

c)



$$Q_H = 30\text{J}, Q_C = 20\text{J}, W_{out} = 10\text{J}$$

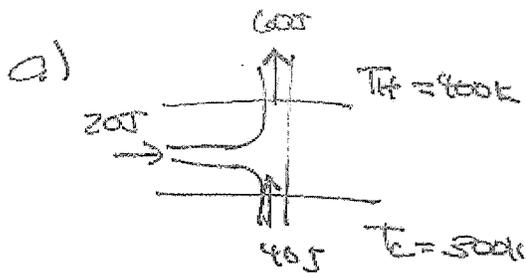
$$\text{First Law OK: } W_{out} + Q_C = 10\text{J} + 20 = 30\text{J} =$$

$$Q_H = 30\text{J} \checkmark$$

$$e_{max} = \frac{1}{2} = 0.5 \text{ since } T_C = 300\text{K}, T_H = 600\text{K}$$

$$e = \frac{W_{out}}{Q_H} = \frac{10\text{J}}{30\text{J}} = \frac{1}{3} = 0.33 \text{ so } 2^{\text{nd}} \text{ Law OK too.}$$

#8 Which Heat Pumps Violate 1<sup>st</sup> or 2<sup>nd</sup> Law?



$$W_{in} = 20\text{J}, Q_C = 40\text{J}, Q_H = 60\text{J}$$

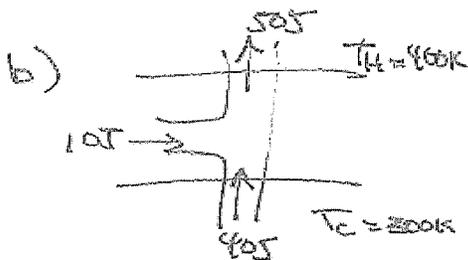
$$1^{\text{st}} \text{ Law: } W_{in} + Q_C = Q_H$$

$$20\text{J} + 40\text{J} = 60\text{J} = Q_H \checkmark$$

1<sup>st</sup> Law OK

$$2^{\text{nd}} \text{ Law: } COP_{\text{max}} = \frac{T_C}{T_H - T_C} = \frac{300\text{K}}{400\text{K} - 300\text{K}} = \frac{300}{100} = 3$$

$$\text{Here } COP = \frac{T_C}{W_{in}} = \frac{40\text{J}}{20\text{J}} = 2, \text{ so } 2^{\text{nd}} \text{ Law OK too.}$$

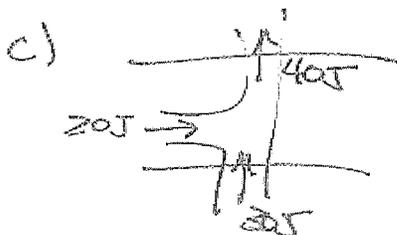


$$W_{in} = 10\text{J}, Q_C = 40\text{J}, Q_H = 50\text{J}$$

$$1^{\text{st}} \text{ Law: } 10\text{J} + 40\text{J} = 50\text{J} = Q_H \checkmark \text{ OK}$$

$$2^{\text{nd}} \text{ Law } COP_{\text{max}} = 3, \text{ COP} = \frac{40\text{J}}{10\text{J}} = 4$$

Violates 2<sup>nd</sup> Law.

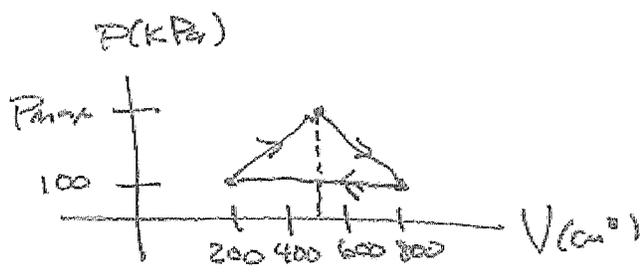


$$W_{in} = 20\text{J}, Q_C = 30\text{J}, Q_H = 40\text{J}$$

$$W_{in} + Q_C = 20\text{J} + 30\text{J} = 50\text{J}$$

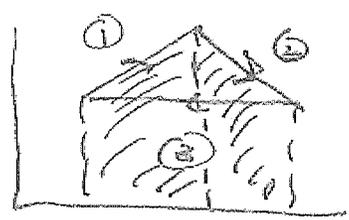
but  $Q_H = 40\text{J}$ , Violates First Law.

#9



$W_{gas} = 60 J$   
 what is  $P_{max}$ ?

$W_{gas}$  is Area under graph with increasing Volume = Positive Work  
 AND Decreasing Volume  $\Rightarrow$  Negative Work



Positive Negative  
 $W_{gas} = W_1 + W_2 + W_3$

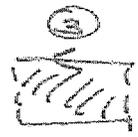
$W_1 = \text{Left triangle} + \text{rectangle}$



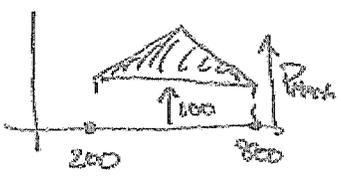
$W_2 = \text{Right triangle} + \text{rectangle}$



$W_3 = \text{bottom } \cancel{\text{triangle}} \text{ rectangle}$



Since  $W_3$  Negative for cycle  $W_{gas} = \text{Area of "top" Triangle}$



$$W_{gas} = \frac{1}{2}(800-200)(P_{max}-100) = \frac{1}{2}(600)(P_{max}-100)$$

but  $V$  in  $cm^3$  AND  $P$  in  $kPa$ . Need  $m^3$  AND  $Pa$  to get  $J$

$$1\text{m}^3 = (1\text{m})(1\text{m})(1\text{m}) = (100\text{cm})(100\text{cm})(100\text{cm}) = 1 \times 10^6 \text{cm}^3$$

↑  
1 million

$$600\text{cm}^3 \times \frac{1\text{m}^3}{1 \times 10^6 \text{cm}^3} = 6 \times 10^{-4} \text{m}^3$$

$$100\text{KPa} = 100(1000)\text{Pa} = 100,000\text{Pa}$$

$$\begin{aligned} \therefore W_{\text{gas}} &= \frac{1}{2} (6 \times 10^{-4} \text{m}^3) (P_{\text{max}} - 100,000\text{Pa}) \\ &= (3 \times 10^{-4} \text{m}^3) P_{\text{max}} - 30\text{J} \end{aligned}$$

$$W_{\text{gas}} = 60\text{J} \Rightarrow 60\text{J} = (3 \times 10^{-4} \text{m}^3) P_{\text{max}} - 30\text{J}$$

$$\Rightarrow P_{\text{max}} = \frac{90\text{J}}{3 \times 10^{-4} \text{m}^3} = 300,000\text{Pa} = 300\text{KPa}$$

↓

$$\text{Unit: } \frac{\text{J}}{\text{m}^3} = \frac{\text{N} \cdot \text{m}}{\text{m}^3} = \text{N/m}^2 = \text{Pa}$$

#10

Gas is Compressed from  $600\text{cm}^3 = V_i$  to

$200\text{cm}^3 = V_f$  at  $p = 400\text{kPa} \leftarrow$  constant.

At SAME TIME  $100\text{J}$  of heat transferred out  $\Rightarrow Q = -100\text{J}$

FIND  $\Delta E_{\text{TH}}$

1st Law:  $Q + W = \Delta E_{\text{TH}}$

but  $W = -W_{\text{gas}} \Rightarrow Q - W_{\text{gas}} = \Delta E_{\text{TH}}$

Constant Volume  $\Rightarrow W_{\text{gas}} = p \Delta V$  but  $\Delta V$  must be in  $\text{m}^3$   
and  $p$  is Pa

$$\Delta V = 200\text{cm}^3 - 600\text{cm}^3 = -400\text{cm}^3 \times \frac{1\text{m}^3}{1 \times 10^6 \text{cm}^3} = -4 \times 10^{-4} \text{m}^3$$

See any other  
problem in this solution  
set

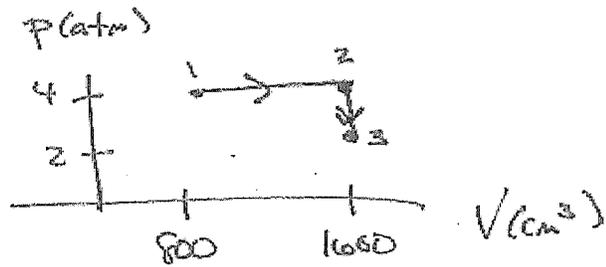
$$400\text{kPa} = 400(1000\text{Pa}) = 400,000\text{Pa}$$

$$\therefore W_{\text{gas}} = 400,000\text{Pa} (-4 \times 10^{-4} \text{m}^3) = -160\text{J}$$

$$Q - W_{\text{gas}} = \Delta E_{\text{TH}} \Rightarrow -100\text{J} - (-160\text{J}) = \Delta E_{\text{TH}}$$

$$\Rightarrow \Delta E_{\text{TH}} = -100\text{J} + 160\text{J} = 60\text{J}$$

#11



$n = 0.1 \text{ mol}$  ← why???

a) How much heat is transferred from 1 → 2?

THERE ARE TWO WAYS TO DO THIS: Just using the info from class, we would use 1st Law:  $Q + W = \Delta E_{TH}$

$$W = -W_{gas} \Rightarrow Q - W_{gas} = \Delta E_{TH}$$

$$\text{Ideal Gas} \Rightarrow \Delta E_{TH} = \frac{3}{2} N k_B \Delta T = \frac{3}{2} n R \Delta T \Rightarrow Q - W_{gas} = \frac{3}{2} n R \Delta T$$

Looking in the textbook, in a section we didn't do we see that for a monatomic

gas under constant pressure:  $Q = n C_p \Delta T$  AND

$$C_p = \frac{5}{2} R \Rightarrow Q = \frac{5}{2} n R \Delta T$$

$$\text{Start with } Q - W_{gas} = \frac{3}{2} n R \Delta T$$

$$\text{Constant pressure} \Rightarrow W_{gas} = p \Delta V$$

$$p = 4 \text{ atm} \times \frac{101300 \text{ Pa}}{\text{atm}} = 405200 \text{ Pa}$$

$$\Delta V = 1600 \text{ cm}^3 - 800 \text{ cm}^3 = 800 \text{ cm}^3 \times \frac{\text{m}^3}{10^6 \text{ cm}^3} = 8 \times 10^{-4} \text{ m}^3$$

$$W_{\text{gas}} = (405200 \text{ Pa})(8 \times 10^{-4} \text{ m}^3) = 324.16 \text{ J}$$

$$DE_{\text{TH}} = \frac{3}{2} n R \Delta T = \frac{3}{2} n R (T_2 - T_1)$$

So find  $T_1$  ~~from~~  $P_i V_i = n R T_i \Rightarrow T_i = \frac{P_i V_i}{n R}$

$$\therefore T_1 = \frac{(405200 \text{ Pa})(800 \text{ cm}^3)}{(0.1 \text{ mol})(8.31 \text{ J/mol}\cdot\text{K})} = \frac{324.16 \text{ J}}{(0.1 \text{ mol})(8.31 \text{ J/mol}\cdot\text{K})} = 390 \text{ K}$$

Unit:  $\frac{\text{J}}{\frac{\text{mol}\cdot\text{J}}{\text{mol}\cdot\text{K}}} = \frac{1}{\text{K}} = \text{K}$

To find  $T_2$  simply use the fact that since  $N$  and  $P$  <sup>are</sup> constant  $\Rightarrow$

$$\frac{P V_i}{T_1} = \frac{P V_2}{T_2} \Rightarrow T_2 = \left(\frac{V_2}{V_i}\right) T_1$$

$$T_2 = \left(\frac{1600}{800}\right) T_1 = 2 T_1 \leftarrow \text{Doubling Volume, Doubles Temp when pressure is constant}$$

$$\therefore T_2 = 780 \text{ K}$$

$$\Delta E_{TH} = \frac{3}{2} n R (T_2 - T_1) = \frac{3}{2} (0.1 \text{ mole}) \left( \frac{8.31 \text{ J}}{\text{mole K}} \right) (780 \text{ K} - 390 \text{ K})$$

$$= \frac{3}{2} (0.1 \text{ mole}) \left( \frac{8.31 \text{ J}}{\text{mole K}} \right) (390 \text{ K}) = 486.345 \text{ J}$$

$$Q - W_{\text{gas}} = \Delta E_{TH} \Rightarrow Q - 324.16 \text{ J} = 486.345 \text{ J}$$

$$\Rightarrow Q = 486.345 \text{ J} + 324.16 \text{ J} = 810.505 \text{ J} = 810 \text{ J}$$

to 2 sig figs

Alternatively  $Q = \frac{5}{2} n R \Delta T = \frac{5}{2} (0.1 \text{ mole}) \left( \frac{8.31 \text{ J}}{\text{mole K}} \right) (780 \text{ K} - 390 \text{ K})$

$$= 810 \text{ J}$$

b) From 2  $\rightarrow$  3 ?

Here ~~gas~~, there <sup>really</sup> ~~are~~ <sup>only one</sup> way  $\odot$   $Q - W_{\text{gas}} = \Delta E_{TH}$

From 2  $\rightarrow$  3,  $V = 1600 \text{ cm}^3$  constant  $\Rightarrow W_{\text{gas}} = 0$

$$\therefore Q = \Delta E_{TH} = \frac{3}{2} n R \Delta T$$

The book gives  $Q = n C_V \Delta T$  where  $C_V = \frac{3}{2} R$

SO SAME AS BEFORE (AND WHERE BOOK'S EQUATION  
(CAME FROM))

$$Q = \frac{3}{2} nR \Delta T = \frac{3}{2} nR (T_3 - T_2)$$

$$T_2 = 780 \text{ K}, \text{ to find } T_3$$

$$\frac{P_2 V_2}{T_2} = \frac{P_3 V_3}{T_3} \quad V_2 = V_3$$

$$\therefore T_3 = T_2 \left( \frac{P_3}{P_2} \right) = T_2 \left( \frac{2}{4} \right) = \frac{1}{2} T_2 \leftarrow \text{cutting pressure in half while volume is constant, cuts temp. in half}$$

$$\therefore T_3 = 390 \text{ K}$$

$$Q = \frac{3}{2} (0.1 \text{ mole}) (8.31 \text{ J/mole} \cdot \text{K}) (390 \text{ K} - 780 \text{ K}) = \frac{3}{2} (0.1 \text{ mole}) (8.31 \text{ J/mole} \cdot \text{K}) (-390 \text{ K})$$

$$\Rightarrow Q = -486.135 \text{ J} = -\overset{-486 \text{ J}}{\cancel{486.135 \text{ J}}}$$

c) What is total change in thermal energy?

$$\Delta E_{\text{TOTAL}} = \frac{3}{2} nR (T_3 - T_1) \quad \text{since } T_3 = T_1 = 390 \text{ K}$$

$$\Delta E_{\text{TOTAL}} = 0$$

$$\text{OR } \Delta E_{\text{TH, 1} \rightarrow 2} + 486 \text{ J} \quad \Delta E_{\text{TH, 2} \rightarrow 3} = -486 \text{ J} \Rightarrow \Delta E_{\text{TOTAL}} = 486 \text{ J} - 486 \text{ J}$$