Name: ____________________ ID: __________ ~~Lab~~ (day/time): __________

Physics 202
Midterm Exam 2
2/20/2019

Collaboration is not allowed. Allowed on your desk are: up to ten 8.5 x 11 inch doubled sided sheets of notes that are bound together, non-communicating scientific calculator, 1 page of scratch paper, writing utensils, and the exam. You will have 80 minutes to complete this exam.

> Useful constants:
>
> $\rho_{water} = 1000 \frac{kg}{m^3}$ $\rho_{air} = 1.225 \frac{kg}{m^3}$ $g = 9.81 \frac{m}{s^2}$ $0^\circ C = 273.15\,K$
>
> $P_{atm} = 101,325\,Pa$

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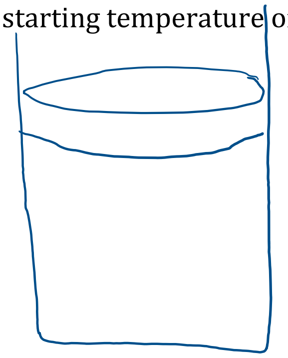
1. (6 points) A cylinder is *sealed* with a piston inserted into the top. An unknown number of moles of ideal monatomic gas is contained within such that it is *isolated* from the surrounding environment.

(a) The gas is compressed to one half of its original volume. If the pressure in the gas remained constant at 200 *kPa* and the temperature changed by 200 $^\circ C$, what was the starting temperature of the gas?



$P_0 V_0 = nRT_0$

$P_1 V_1 = nRT_1$

⇓

$P_0 \frac{1}{2} V_0 = nRT_1$

$\Rightarrow T_1 = \frac{1}{2}\frac{P_0 V_0}{nR} = \frac{1}{2} T_0$

$\Delta T = 200\,K$

$T_0 - T_1 = 200\,K$

$T_0 - \frac{1}{2}T_0 = 200\,K$

$\Rightarrow \frac{1}{2}T_0 = 200\,K$

$\Rightarrow \boxed{T_0 = 400\,K}$

(b) The cylinder has a radius of 5 *cm*, and the piston started at a height of 10.0 *cm*. How many moles of gas are in the cylinder?

initial Vol = (Area)(height)

$= (\pi r^2)(h)$

$= \pi (0.05)^2 (0.1)$

$= 0.000785\,m^3$

$P_0 V_0 = nRT_0$

$(200\,000\,Pa)(0.000785\,m^3) = n\left(8.314 \frac{kg\,m^2}{K\,s^2}\right)(400\,K)$

$\boxed{n = 0.047\,mol}$

For questions 2 through 4 **fill in the square** next to all correct answers, a given problem may have more or less than one correct answer. Each correctly chosen answer will receive two points. There are 4 correct answers in this section and only the first 4 filled in answers will be graded. There is no partial credit.

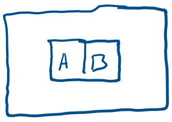
2. Two objects in a sealed container are brought into contact with each other. Object A has a temperature of 400 K. Object B has a temperature of 200 K. The specific heat of object B is twice that of A. The mass of object A is one third that of object B. The final temperature of the system is...

a. Less than 300 K.

b. greater than 300 K.

c. equal to 300 K.

d. We cannot solve with the given information.



$\Delta E_A = -\Delta E_B$ $C_B > C_A$

$\Delta E = cm\Delta T$ $m_B > m_A$

$C_A m_A \Delta T_A = C_B m_B \Delta T_B$ (small, big, big, small)

3. Which of the following Sankey diagrams depict thermodynamic cycles that do not violate the first or second laws of thermodynamics?

a.

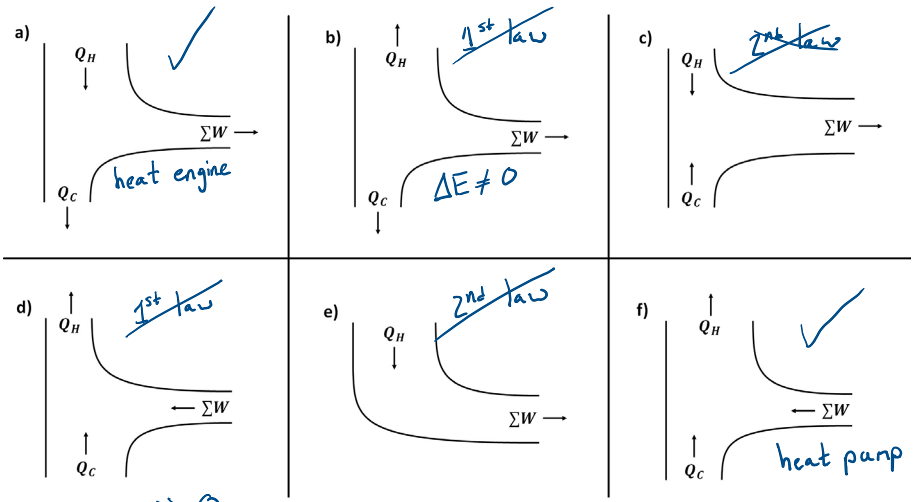
b.

c.

d.

e.

f.



$Q_c + \Sigma W \gg Q_H$

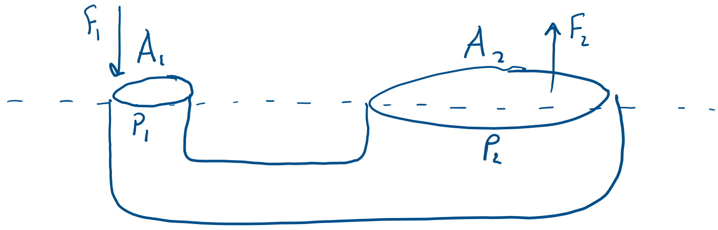
4. A hydraulic press is created with piston 1 having a radius R_1, and piston 2 having a radius R_2. Which of the following will result in a mechanical advantage of 4 when you push on piston 1?

a. $R_1 = 2\ cm$, $R_2 = 8\ cm$

b. $R_1 = 1\ cm$, $R_2 = 4\ cm$

c. $R_1 = 1\ cm$, $R_2 = 2\ cm$

d. $R_1 = 2\ cm$, $R_2 = 1\ cm$



mech. adv. $\Rightarrow F_2 = 4F_1$

$\Rightarrow P_2 A_2 = 4 P_1 A_1$ but $P_1 = P_2$

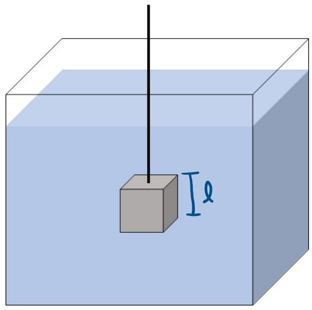
$\Rightarrow A_2 = 4A_1$

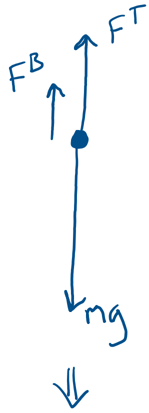
$\Rightarrow \pi R_2^2 = 4\pi R_1^2$

$\Rightarrow R_2^2 = 4R_1^2$

$R_2 = 2R_1$

5. **(8 points)** On Earth, a cube is suspended so that it's top surface is 10.0 meters under water by a rope as pictured. The water exerts a force on the top of the cube of 1000.0 N. If the tension in the string is 100.0 N, what is the density of the cube? (Drawing may not be to scale!)





$$F_{top} = P_{top} A = (P_{atm} + \rho_f g d)\, \ell^2$$

$$\Rightarrow 1000 = \left[101{,}325 + (1000)(9.8)(10)\right] \ell^2$$

$$\Rightarrow 1000 = 199{,}325\, \ell^2$$

$$\Rightarrow \ell = 0.071\,m = 7.1\,cm$$

$$\Rightarrow V_{cube} = \ell^3 = 3.55 \times 10^{-4}\, m^3$$

$\Downarrow$

$$F^B + F^T = mg$$

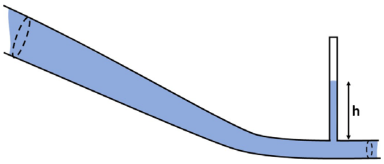
$$\Rightarrow \rho_f V_{cube}\, g + (100\,N) = \rho_{cube} V_{cube}\, g$$

$$\Rightarrow \rho_f + \frac{100\,N}{V_c\, g} = \rho_c$$

$$\Rightarrow 1000 \frac{kg}{m^3} + \frac{100\,N}{(3.55 \times 10^{-4})(9.8)} = 2.97 \times 10^{4} \frac{kg}{m^3} \Rightarrow \text{really dense!}$$

(white dwarf ~ 10^9 kg/m³
lead ~ 11,000 kg/m³
neutron star ~ 10^{17} kg/m³ !!)

6. **(8 points)** A pipe carrying water from an elevated lake to a city has an inlet from the lake which is 9.81 meters below the water level of the lake and has a cross sectional area of 0.5 m^2. Water enters the inlet with a speed of 0.3 m/s. The pipe descends 10 meters before reaching the city. An evacuated cylinder is connected vertically to the 10.0 cm radius pipe near the city outlet to measure the water pressure. What is the height, **h**, of the water inside the cylinder?



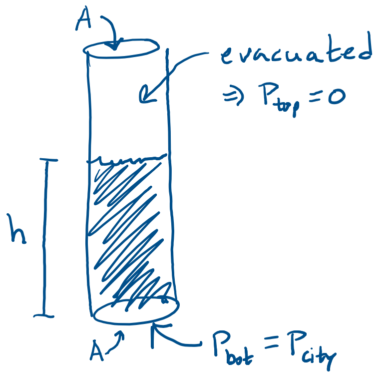
$$P_{lake} + \rho_w g y_{lake} + \frac{1}{2}\rho_w v_{inlet}^2 = P_{city} + \rho_w g y_{city} + \frac{1}{2}\rho_w v_{city}^2$$

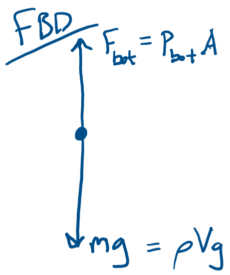
$$P_{lake} = P_{atm} + \rho g d$$
$$= 101{,}325 \tfrac{N}{m^2} + (1000 \tfrac{kg}{m^3})(9.81 \tfrac{m}{s^2})(9.81 m)$$
$$P_{lake} = 197{,}561 \text{ Pa}$$

$$A_{inlet} v_{inlet} = A_{city} v_{city}$$
$$\frac{(0.5 m^2)(0.3 m/s)}{\pi (0.1 m)^2} = v_{city}$$
$$\Rightarrow v_{city} = 4.77 \text{ m/s}$$

Set city as origin

$$\Rightarrow P_{city} = P_{lake} + \rho g y_{lake} + \frac{1}{2}\rho v_{lake}^2 - \rho g y_{city} - \frac{1}{2}\rho v_{city}^2$$
$$= 197{,}561 \text{ Pa} + (1000 \tfrac{kg}{m^3})(9.81 \tfrac{m}{s^2})(10 m) + \tfrac{1}{2}(1000 \tfrac{kg}{m^3})(0.3 \tfrac{m}{s})^2 - \tfrac{1}{2}(1000 \tfrac{kg}{m^3})(4.77 \tfrac{m}{s})^2$$
$$= 284{,}329 \text{ Pa}$$

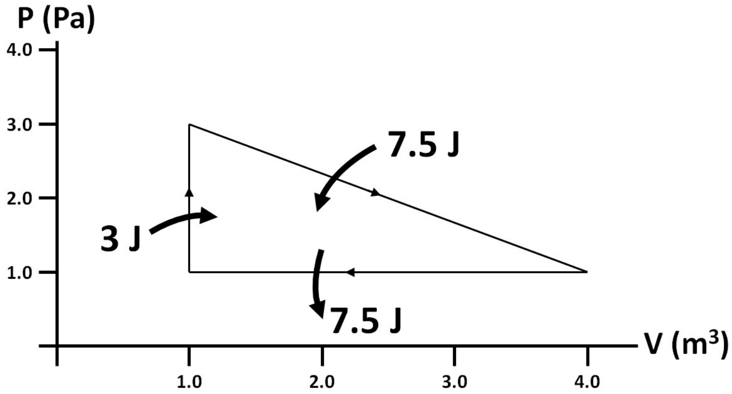




$$F_{net} = 0 \Rightarrow P_{bot} A = \rho_w V_{cyl} g$$
$$\Rightarrow P_{bot} A = \rho_w A h g$$
$$\Rightarrow P_{bot} = \rho_w h g$$
$$\Rightarrow h = \frac{P_{bot}}{\rho_w g} = \frac{284{,}329 \text{ Pa}}{(1000 \tfrac{kg}{m^3})(9.81 \tfrac{m}{s^2})}$$

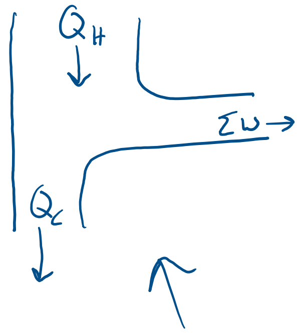
$$\boxed{h = 28.9 \text{ m}}$$

7. **(6 points)** A monatomic ideal gas is taken through the following three process cycle in a sealed container. The heat entering and leaving the system is also illustrated.



(a) What is the efficiency or what are the coefficients of performance for this cycle?

heat engine ⇒ efficiency ⇒ $\frac{|\Sigma W|}{|Q_H|}$



$Q_H = 7.5\,J + 3\,J = 10.5\,J$

ΣW = area of triangle $= \frac{1}{2}(3\,m^3)(2\,Pa)$

$= 3\,J$

$\Rightarrow \text{eff} = \frac{3\,J}{10.5\,J} = 28.6\%$

Q_H is +

Q_c is −

(b) If the cold reservoir is at 300 K, and the process is running at its maximum possible efficiency/CoP, what is the temperature of the hot reservoir?

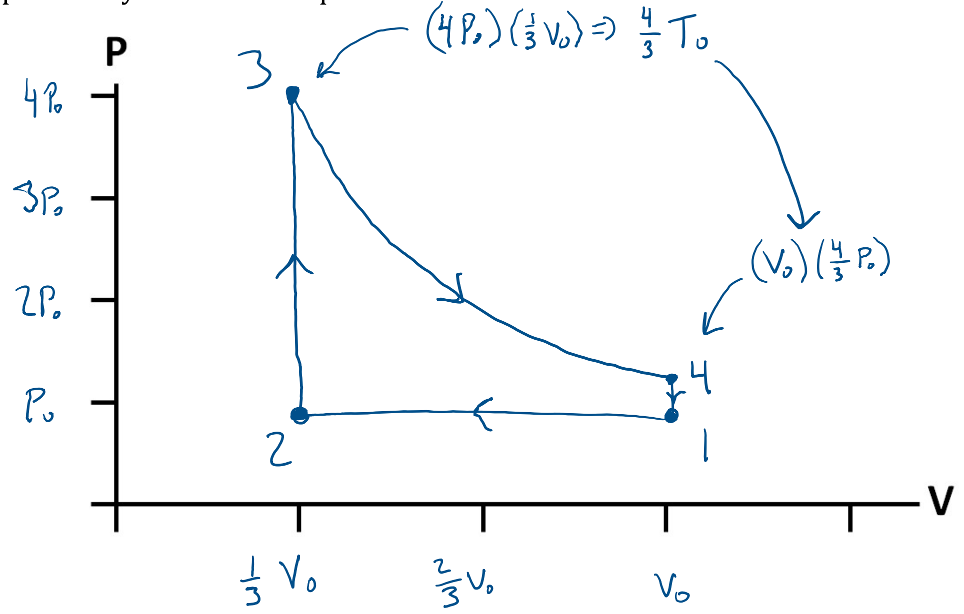
Max eff. $= 1 - \frac{T_c}{T_H} = 0.286$

$\Rightarrow \frac{T_c}{T_H} = 0.714$

$\Rightarrow \boxed{T_H = 420\,K}$

8. A sealed container of monatomic ideal gas undergoes the following processes. First, it is compressed in an isobaric process resulting in a temperature one third of the starting temperature. Second, it is put through an isochoric process resulting in a quadrupling of the pressure. Third, it is taken back to its original volume via a isothermal process. Fourth, it follows an isochoric process back to its original pressure and volume.

(a) **(2 points)** Draw a PV diagram of the cycle. Label the starting point with a 1, the end of the second process with a 2, and so on. You should have four labeled points separated by the described processes above.



(b) **(5 points)** Fill in the table below with the pressures, temperatures, and volumes at each equilibrium state between processes (points 1, 2, 3, and 4).

Point	Pressure	Volume	Temperature
1	2 kPa	1.2 m^3	600 K
2	2 *kPa*	0.4 m^3	200 K
3	8 kPa	0.4 m^3	800 K
4	2.67 kPa	1.2 m^3	800 K

8. (continued)

(c) (3 points) What is the thermal energy change during the first process? (between points 1 and 2)

$PV = nRT$

$(2000)(1.2) = n(8.31)(600)$

$\Rightarrow n = 0.48$

$\Delta E = \frac{3}{2} nR\Delta T$

$= \frac{3}{2}(0.48)(8.31)(-400)$

$= -2{,}400\ J$

(d) (3 points) How much heat enters or leaves the system during the first process? (between points 1 and 2)

$\Delta E = W + Q$

$-2400\ J = +1600\ J + Q$

$\Rightarrow Q = -4000\ J$

negative $\Rightarrow$ leaves

$W_{1\to 2} = -P\Delta V$

$= -(2000)(0.4 - 1.2)$

$= +1600\ J$

(e) (3 points) Fill in the following table with the **signs (+, −, or 0)** of the change in thermal energy, work, and heat for each process.

Process	$\Delta E_{thermal}$	W_{ongas}	Q
1 → 2	−	+	−
2 → 3	+	0	+
3 → 4	0	−	+
4 → 1	−	0	−