Name:______________________________ ID:______________________________

Physics 202

Midterm Exam 2

2/16/2022

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

Constants

$k_B = 1.38 \times 10^{-23}$ J/K

$R = 8.31$ J/mol·K

$m_{nitrogen} = 4.65 \times 10^{-26}$ kg

$p_{atm} = 101{,}300$ Pa

1 cal = 4.19 J

1 liter = 1×10^{-3} m^3,

$c_{water} = 4190$ J/kg·K

$c_{ice} = 2090$ J/kg·K

$L_{f,water} = 3.33 \times 10^5$ J/kg

$L_{v,water} = 22.6 \times 10^5$ J/kg

$\sigma = 5.67 \times 10^{-8}$ W/m^2·K^4

$\rho_{air} = 1.28$ kg/m^3

$\rho_{water} = 1000$ kg/m^3

For questions 1 through 4 **fill in the square** next to all correct answers. A given problem may have more than one correct answer. Each correctly bubbled answer will receive two points. There are **8** correct answers in this section and only the first **8** filled in answers will be graded. There is no partial credit.

1. The weight of water displaced by a large cargo ship when placed in the ocean was found to be 990 million Newtons. What is the weight (force of gravity) of the cargo ship?

   x (a) 990 million Newtons.
   □ (b) More than 990 million Newtons.
   □ (c) Less than 990 million Newtons
   □ (d) 990 million kg
   □ (e) 101 million kg
   □ (f) 9,702 million kg

2. Which of the following mechanisms can be used by the International Space Station to transfer thermal energy from its hot components to the cold environment, which is the vacuum of space?

   □ (a) Conduction.
   □ (b) Convection.
   x (c) Radiation.
   □ (d) Work.

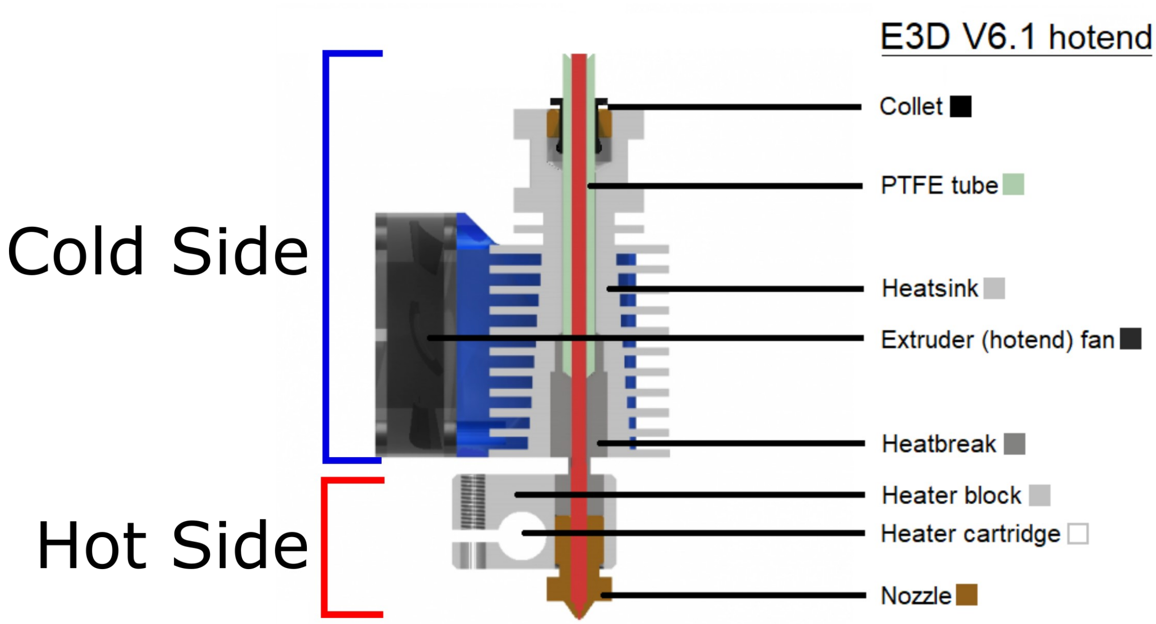
3. A balloon filled with helium, and made from thermally conductive rubber, is in thermodynamic equilibrium with its surroundings, at 150 meters deep in the ocean. It is moved very slowly upwards to 10 meters beneath the surface. It remains at equilibrium with the surrounding water during this motion. Assume the water temperature is constant as a function of ocean depth (a pretty good assumption within 200 meters of the surface!). Which of the following statements must be true?

   □ (a) The helium goes through an adiabatic process
   □ (b) The helium goes through an isochoric process
   x (c) The helium goes through an isothermal process
   □ (d) The helium goes through an isobaric process
   □ (e) The pressure in the helium increases
   x (f) The pressure in the helium decreases
   □ (g) The pressure in the helium is constant
   x (h) The volume of the helium increases
   □ (i) The volume of the helium decreases
   □ (j) The volume of the helium is constant
   □ (k) The work done on the helium is positive
   x (l) The work done on the helium is negative
   □ (m) The work done on the helium is zero
   x (n) The heat into the helium is positive
   □ (o) The heat into the helium is negative
   □ (p) The heat into the helium is zero

4. While walking the dog River in the snow we noticed that he could stay on top of the hard snow and not fall through, except when he lifted his leg to pee. Whenever he would do this, he would break through the top layer of snow, and fall a few inches into it. This was much to his surprise. Which physics phenomena best account for this observation?

   □ (a) Energy
   □ (b) Acceleration
   x (c) Pressure
   □ (d) Velocity
   □ (e) Momentum

5. (5 points) One type of a 3D printer uses solid plastic cylindrical tubes that pass through a **hotend**. A **hotend** contains a cold side and a hot side. The solid plastic cylindrical tube enters the cold side of the **hotend** as a solid, and as it reaches the hot side of the **hotend**, it melts as it leaves the nozzle. Let's explore the thermal energy management of the **hotend** shown below. Note that there is a fan that blows air across the cold side of the **hotend**, and the cold side is connected to the hot side via a metal piece.



(a) The hot side of the **hotend** is around 215 degrees Celsius. Some of the thermal energy from the hot side transvers via heat to the cold side. Which heat mechanism(s) (Conduction, Convection, Radiation) are used to transfer the thermal energy from the hot side to the cold side? Explain your reasoning.

Conduction: The hot side is connected to the cold side via a metal piece. Metals have large thermal conductivities.

Radiation: The hot side has a large temperature compared to surrounding, and a large temperature overall. So more radiation leaves the hot side than enters it.

Convection: Possibly some convection currents due to the dramatic temperature change in a small distance.

(b) The cold side is able to remain at room temperature because some of the thermal energy is transferred via heat to the environment. Which heat mechanism(s) (Conduction, Convection, Radiation) are used to transfer the thermal energy from the cold side to the environment? Explain your reasoning.

Conduction: Not much conduction because air surrounds the cold side, and air has a small thermal conductivity.

Radiation: Some radiation.

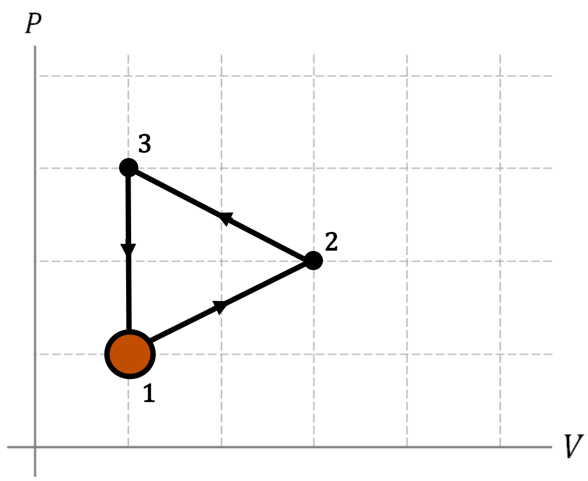
Convection: There is a fan that moves room temperature air across the cold side components moving the hotter air around the cold side to the environment.

6. (12 points) 1.0×10^{-3} moles of monatomic ideal gas is contained in a cylinder of volume 10 cm^3 at 240,000 Pa of pressure. Call this equilibrium state 1 (orange dot on diagram). The gas is put through the following processes (**assume these processes follow straight lines on a PV diagram**):

1→2: The volume of the container triples while the pressure in the gas doubles.
2→3: The volume of the container returns to its original volume while the pressure increases by a factor of 3/2
3→1: The gas returns from equilibrium state 3 to its original pressure and volume of equilibrium state 1

Note: There is a list of constants on the front page.

(a) Carefully draw this cycle, **to scale**, on the following PV diagram.

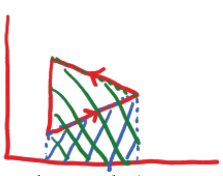


(b) Which of the processes, 1→2, 2→3, and 3→1 are named processes we have discussed this term (adiabatic, isothermal, isochoric, or isobaric)? Give the name(s) and explain your answers.

3→1 is isochoric b/c the volume is constant

1→2 & 2→3 are not named processes b/c T, P, V are not constant & they do not have the curve of an adiabat ($Q \neq 0$)

(c) Is this a heat engine or a heat pump? Explain your answer without using counter-clockwise or clockwise.



green area under curve is + work b/c gas is compressed ⇒ work done on gas by env.

blue area is − work b/c gas is expanding ⇒ work done by gas on environment

green area is bigger ⇒ net + work done on gas ⇒ heat pump

(d) Find the temperature of the gas at equilibrium state 1.

$PV = nRT$

$$\Rightarrow T = \frac{PV}{nR} = \frac{(240000\ Pa)(10\ cm^3)\left(\frac{1\ m}{100\ cm}\right)^3}{(10^{-3}\ mol)\left(8.314\ \frac{Pa\ m^3}{mol\ K}\right)} = 288\ K$$

(~15°C or ~60°F)

(e) Find the work done on the gas during any two of the three processes. Clearly label for which processes you are calculating the work.

3→1

$W = 0$ b/c

$V = const$

1→2

Area B = $\frac{1}{2}$ area A

area A = $(30\ cm^3 - 10\ cm^3) \times (240{,}000\ Pa)$
= 4.8 J

⇒ $W_{1\to2} = 7.2\ J$

2→3
alternate method

1 square on graph
$= (240000\ Pa)(10\ cm^3)\left(\frac{1\ m^3}{10^6\ cm^3}\right)$
$= 2.4\ J$

$W_{2\to3} = 5$ boxes
$= 12\ J$

7. (6 points) River the space dog is exploring an uncharted planet who's atmosphere is made of pure nitrogen. All of the sudden he is shrunk down to the size and mass of a nitrogen molecule traveling at average (RMS) room temperature speeds.

(a) How fast is River traveling?

Kinetic Theory of Gases

Micro Energy / Particle: $\bar{K} = \frac{1}{2}mv^2$

Macro Energy / Particle: $E_{th}/N = \frac{3}{2}k_B T$

Combine

$\frac{1}{2}mv^2 = \frac{3}{2}k_B T$

$v^2 = \frac{3k_B T}{m}$

w/ $T \approx 293K$, $v = 511\ m/s$

(b) If the temperature increases by a factor of 5, by what factor would the average (RMS) speed of the molecule-sized River change?

$v = \sqrt{\frac{3k_B T}{m}}$ w/ $m = \text{const.}$ $v \propto \sqrt{T}$

if $T \to 5T$

then $v \to \sqrt{5}\, v$

Rubric

(a) Kinetic Theory of Gasses
1 pt - Micro KE equation
1 pt - Macro energy equation
1 pt - setting them equal
0.5 pt - algebra
0.5 pt - correct answer and units

(b) Proportional Reasoning
1 pt - speed proportional to square root of temp
1 pt - application and answer

8. (6 points) A hydraulic system of pistons (see figure) can be used to gain mechanical advantage and lift very heavy objects with significantly less force than directly lifting them. Imagine a system where the pistons have a rectangular cross sectional area instead of the typical circular cross-sectional area. The small piston cross-sectional area is 20 cm x 40 cm while the large piston is 2.5 m x 6 m.

(a) How much force would need to be applied to the smaller piston to lift a 1300-kg car? (**Ignore any height differences in the fluid**)

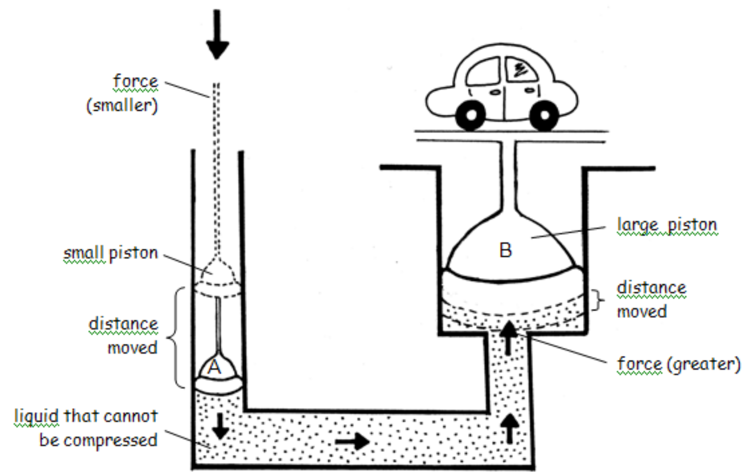


Figure provided by OpenStax.

at same depth in fluid

$P_A = P_B$

So, $\frac{F_A}{A_A} = \frac{F_B}{A_B}$

$F_A = \frac{A_A}{A_B} F_B = \frac{l_A W_A}{l_B W_B} F_B$ (length, width, $M_c g$)

$F_A = \frac{(0.2)(0.4)\,m^2}{(2.5)(6)\,m^2}(1300\,kg)(9.8\,m/s^2)$

$F_A = 68\,N$

(b) Use proportional reasoning, order of magnitude, and/or related quantities sense-making techniques to determine if your answer to (a) is reasonable?

$F_A \propto F_B$, the proportionality constant is $\frac{A_1}{A_2} = 0.0053$

F_A should be 2-3 orders of magnitude smaller than F_B

w/ $F_B = M_c g = 12{,}740\,N$

+ $F_A = 68\,N$,

the two do differ by 2-3 orders of mag.

Rubric

(a) Hydraulic Mechanical Advantage
1 pt - pressures are equal
1 pt - Force/area is equal
1 pt - Area = (length)(width)
1 pt - Algebra and application
0.5 pt - Correct answer and units

(b) Sense-making
1.5 pt - sense-making using one or more of the choices presented