Name:
Student Number:

Science One Physics Midterm #3

February 12, 2013

Questions 1-9: Multiple Choice: 2 points each
Questions: Explain your work: 22 points total

Multiple choice answers:

SOLUTIONS.

#1	
#2	
#3	
#4	
#5	
#6	
#7	
#8	
#9	

Formula sheet at the back (you can remove it)

Question 1: A container of oxygen (O_2) gas and an identical container with neon (Ne) gas are each heated from 273K to 300K (at constant volume), and it is found that the same amount of energy is required in each case. We can say that

O_2: higher molar specific heat since some energy goes to rotational K.E.

A) The number of moles of O_2 is the same as the number of moles of Ne. ∴ same moles would mean O_2 takes more energy

B) The number of moles of O_2 is greater than as the number of moles of Ne.

C) The number of moles of O_2 is less than as the number of moles of Ne.

D) Any of the above are possible

- since same energy, must be less moles O_2

Question 2: Two identical containers are each filled with helium. In the first container, the average speed of the atoms is twice the average speed in the second container. If the gas in each container has the same pressure, we can say that

A) The density in the first container is four times larger

B) The density in the first container is two times larger

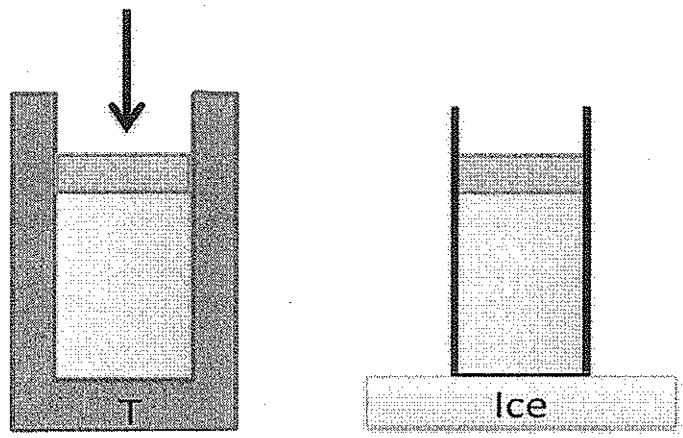
C) The density in the first container is two times smaller

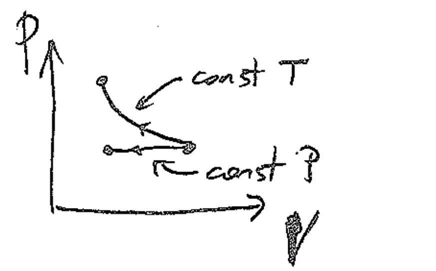
D) The density in the first container is four times smaller

pressure $\propto$ density $\times$ (avg K.E. per molecule)

density $\times \frac{1}{2}mv^2$

if v is double & pressure same, density must be $\frac{1}{4}$





work = area under path.

- greater for const T

Question 3: Two containers each contain one mole of oxygen, each with the same initial volume, temperature, and pressure. One is compressed while being kept at constant temperature, while the other is cooled with a freely moving piston. If the volume is decreased by half in each case, we can say that

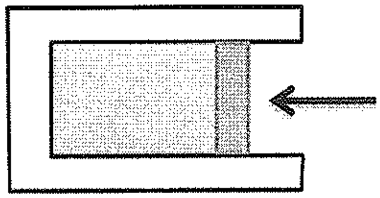
A) The work done on the gas is nonzero in both cases but larger in the constant temperature case

B) The work done on the gas is nonzero in both cases, but smaller in the constant temperature case

C) The work done on the gas is nonzero only in the constant temperature case

D) The work done on the gas is nonzero only in the case where the gas is cooled

other way: Work = $\int P dV$ P increases in the const temp process, so $\text{work}_{(\text{const } T)} > P_0 \Delta V = \text{work (const P)}$



~~Adiabatic:~~
Insulated: $Q = 0$ so $\Delta E = W$
we do work ∴ W +ve, ΔE +ve ∴ temperature increases
Ideal gas Law: $T\uparrow$ $V\downarrow$ so must have $P\uparrow$

Question 4: Gas in an insulated container is compressed. We can say that

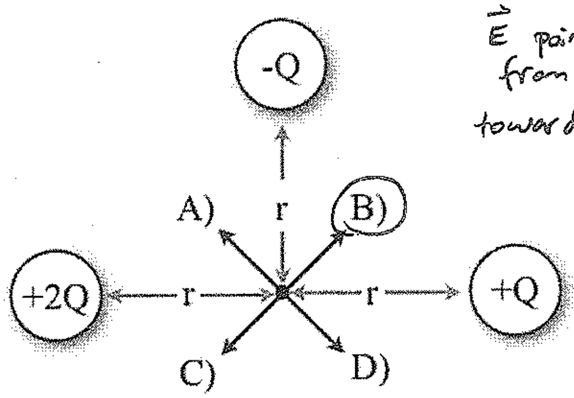
A) The temperature of the gas increases and the pressure stays constant
B) The temperature of the gas stays constant and the pressure increases
C) The temperature and pressure of the gas both increase
D) The temperature of the gas decreases and the pressure increases
E) The temperature and pressure of the gas both decrease

Question 5: Equal amounts of helium gas fill two halves of an isolated container with a thermally conducting partition in the middle. Initially, the temperature is 300K on one side and 400K on the other side. If we observe the gas some time later, we can be sure that the temperatures on the two sides will never be 275K and 425K, because

A) this would violate conservation of energy.
B) this would violate the ideal gas law.
C) the partition allows heat to flow from one side to the other, but the temperatures cannot change if the two gases do not mix.
D) this would be extraordinarily unlikely.

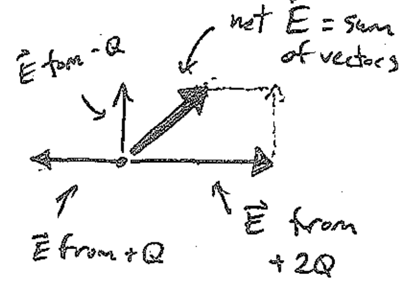
- energy conserved
- only problem is far fewer total states with $T = 275K, 425K$ ∴ going to this config impossibly unlikely
(= violation of 2nd Law)

Question 6: A point in empty space is equidistant from 3 charges as shown. What is the direction of the electric field at that point?



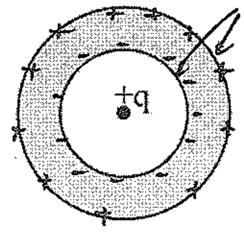
$\vec{E}$ points away from + towards -

size of $\vec{E}$ ∝ Q



E) None of the angles shown

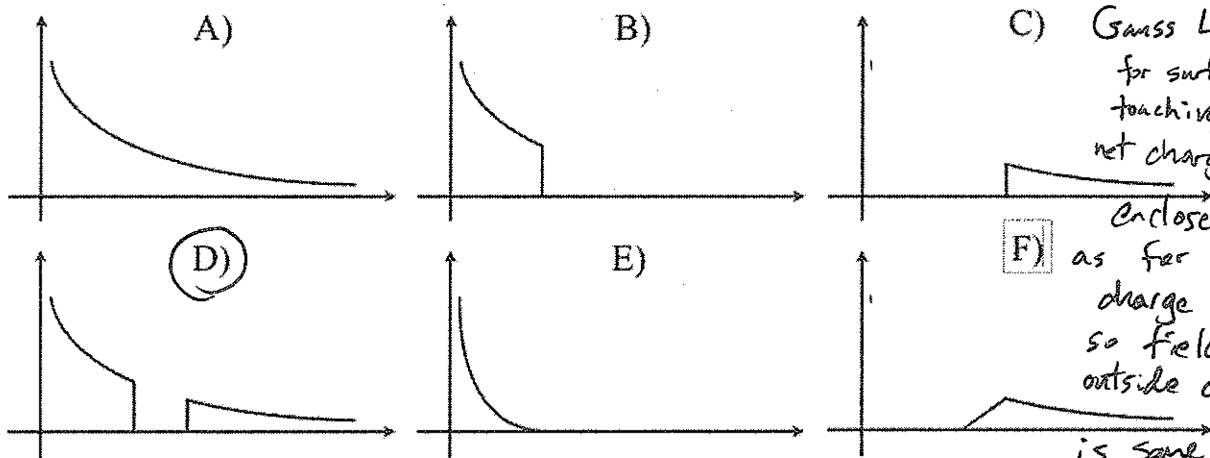
Question 7: A conducting shell has a positive charge sitting inside it, as shown in the figure.



induced charges on surface cancel $\vec{E}$ inside.

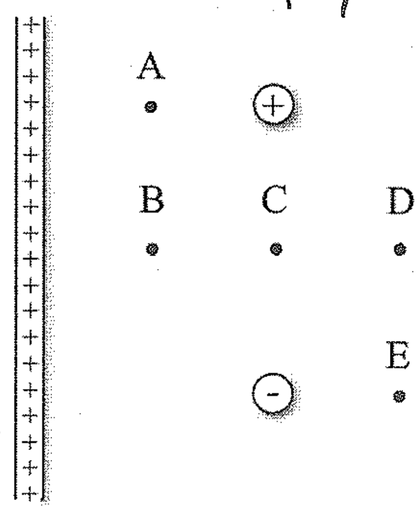
Choose the diagram below that best represents the magnitude of the electric field of this configuration as we move away from the centre.

no field in a conductor.



Gauss Law: for surface not touching conductor, net charges enclosed is same as for point charge at origin, so field everywhere outside conductor is same as for point charge.

Question 8: A proton and an electron sit next to a positively charged plate, as shown in the figure. Rank the combined electric potential from the plate and both charges at each point from highest to lowest.



a) A = B = E > C > D
b) D > C > A = B = E
c) A > B = D = E > C
d) C > B = D = E > A
e) A > B > C > D > E
f) E > D > C > B > A

$V = V_{plate} + V_+ + V_-$

with only plate:

$V_A = V_B > V_C > V_D = V_E$

B, C, D: potentials don't change since equal distance to + & −

A: potential increases from $V_+ + V_-$

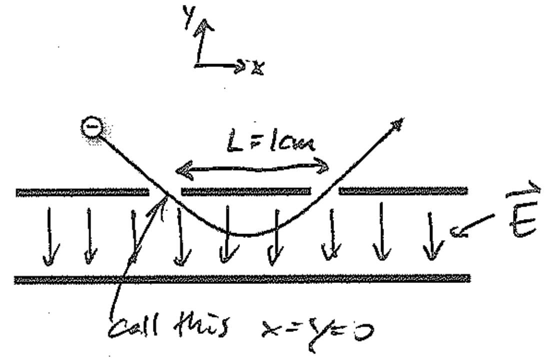
E: potential decreases

Question 9: Two dipoles are held as illustrated in the figure. Which statement best describes the motion of the dipoles when they are released?

will move toward lower energy config: attract.

A) They'll both rotate in the same direction and move away from each other.
B) They'll both rotate in the same direction and move towards each other.
C) They'll both rotate in the same direction and stay stationary with respect to each other.
D) They'll rotate in opposite directions and move away from each other.
E) They'll rotate in opposite directions and move towards each other.
F) They'll rotate in opposite directions and stay stationary with respect to each other.

Question 10 (5 points):



In particle physics experiments it's often useful to make a beam of electrons turn a corner. This can be done using the electric field generated by a parallel plate capacitor.

The figure shows an electron with speed 7×10^6 m/s enters a hole at a 45° angle, travels 1 cm horizontally, and exits at a 45° angle, completing a 90° turn in the process.

Find the strength and the direction of the electric field that bends this electron.

Constant electric field between parallel charged plates, so constant vertical acceleration.

Have: $\Delta X = V_x \Delta t$ where $V_x = 7 \times 10^6 \text{ m/s} \times \cos(45°)$
$= 4.9 \times 10^6 \text{ m/s}$

So the particle travels 1 cm in $\Delta t = \frac{1 \text{ cm}}{4.9 \times 10^6 \text{ m/s}} = 2.0 \times 10^{-9} \text{ s}$

In this time, we need the particle to accelerate vertically from $V_y^i = -4.9 \times 10^6 \text{ m/s}$ to $V_y^f = +4.9 \times 10^6 \text{ m/s}$.

Since the acceleration is constant, we have:

$$a_y = \frac{\Delta V_y}{\Delta t} = \frac{9.8 \times 10^6 \text{ m/s}}{2.0 \times 10^{-9} \text{ s}} = 4.9 \times 10^{15} \text{ m/s}^2$$

For this acceleration, we need a force of

$$F_y = m a_y = (9.1 \times 10^{-31} \text{ kg}) \times (4.9 \times 10^{15} \text{ m/s}^2)$$
$$= 4.5 \times 10^{-15} \text{ N}.$$

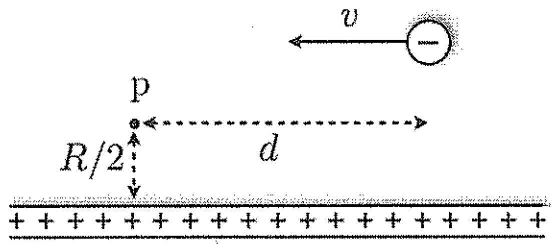
This requires an electric field of

$$E_y = \frac{F_y}{q} = \frac{4.5 \times 10^{-15} \text{ N}}{-1.6 \times 10^{-19} \text{ C}} = -2.8 \times 10^4 \text{ N/C}.$$

(direction is down)

Question 11 (5 points):

An electron is a distance R away from a wire and travelling at velocity v parallel to the wire. After some time the electron has travelled a distance d forward and is now a $R/2$ away from the wire, labelled p on the figure.



A) Given that the electric field of the wire is $E = k\lambda/r$, where λ is the linear charge density (charge per unit length), what is the potential difference between the initial position of the charge and the point p?

We have: $$E_r = -\frac{dV}{dr}$$

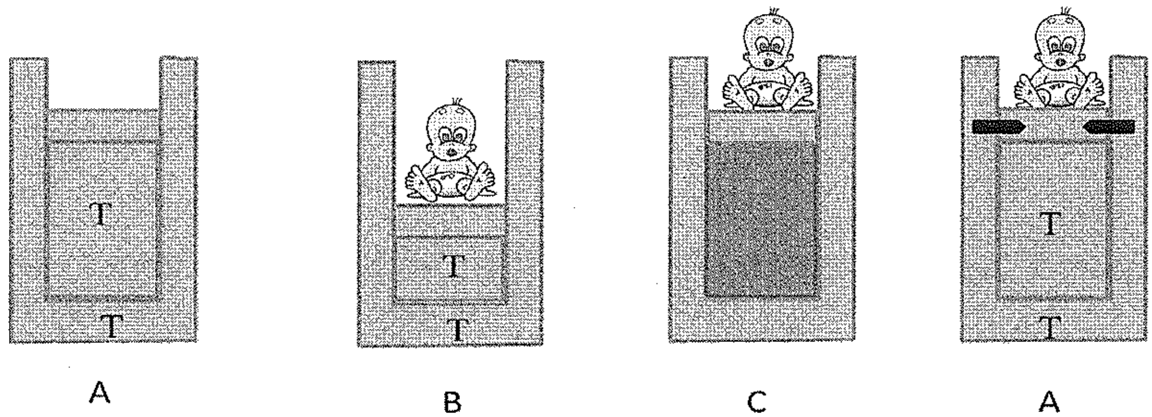
So: $V = -k\lambda \ln(r) + \underbrace{\text{constant}}_{\text{arbitrary.}}$

So: $$\Delta V = V_p - V_{initial}$$
$$= -k\lambda \ln(R/2) - (-k\lambda \ln R)$$
$$= k\lambda(\ln(R) - \ln(R/2))$$
$$\Rightarrow \boxed{\Delta V = k\lambda \ln(2)}$$

B) What is the kinetic energy of the electron at point p?

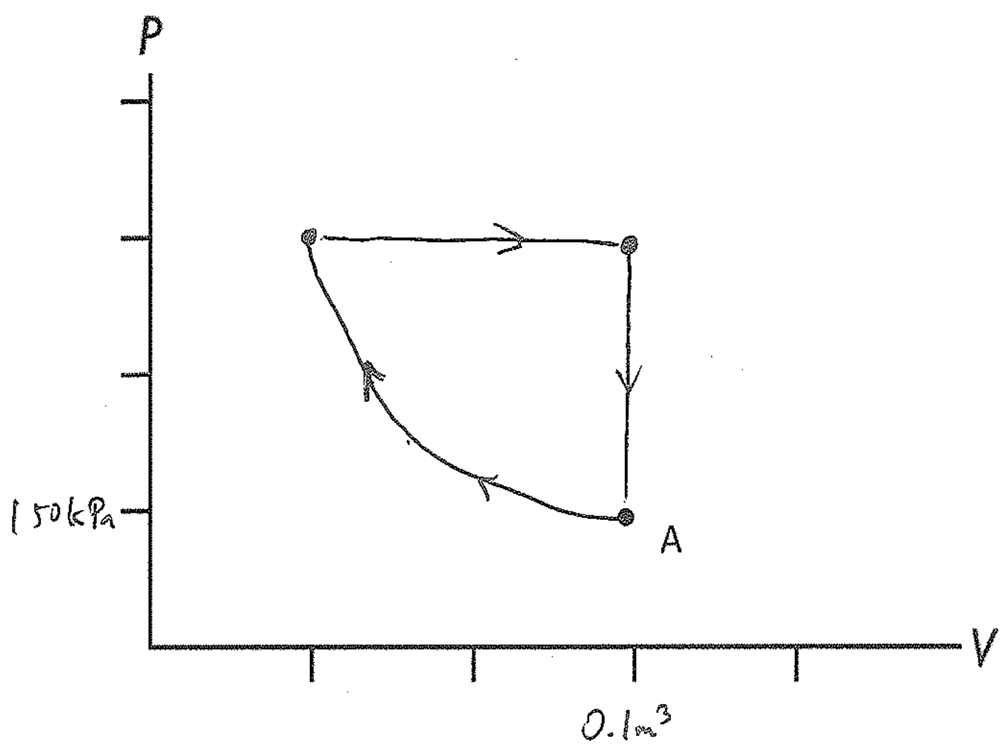
Energy conserved, so

$$\Delta K + \Delta U = 0$$
$$\left(K_p - \tfrac{1}{2} m_e v^2\right) + q\Delta V = 0$$
$$\left(K_p - \tfrac{1}{2} m_e v^2\right) + (-e)(k\lambda \ln(2)) = 0$$
$$\Rightarrow \boxed{K_p = \tfrac{1}{2} m_e v^2 + ke\lambda \ln(2)}$$



Question 12 (8 points):
You are about to submit a patent application for a gasoline-powered device to entertain babies. The device consists of a vertical cylinder of gas with a movable piston surrounded by a constant temperature water bath. The gas inside is originally at the same temperature as the water bath.

To use the device, a baby is placed on top of the piston so that the gas is slowly compressed to one third of its volume at constant temperature (A $\rightarrow$ B). Then fuel is added to the gas and burned slowly so that the gas heats and expands to its original volume while the piston on top is free to move (B $\rightarrow$ C). Finally, the piston is locked and the gas cools again to the temperature of the water bath (C $\rightarrow$ A). The piston locks are removed and the process repeats. The baby is entertained by the gentle up and down motion. (*see next page for questions*)



a) Draw the process on the graph above and fill in the chart below given the initial values for the state A. Explain your work in the space below the table.

	A	B	C
Temperature	300K	300 K	900 K
Pressure	150kPa	450 kPa.	450 kPa
Volume	$0.1m^3$	$0.0333 m^3$	$0.1 m^3$

A→B : const T

$\therefore$ PV constant (I. Gas Law)

$\therefore$ P triples if $V \Rightarrow V \times \frac{1}{3}$

B→C : const P

$\therefore T/V$ const (ideal gas law)

$\therefore$ T triples if V triples

C→A : constant V.

b) Suppose the gas in the cylinder is argon, with $C_V = 3/2\ R$. How much gasoline (35MJ/L) must be burned each cycle to entertain the baby? (Hint: the question is basically asking how much heat must be added to the gas in the process $B \rightarrow C$).

for $B \rightarrow C$,

$$\Delta E = Q + W$$

Have: $W = -P\Delta V$ (since const pressure)

$$= -3 \times 10^4\ J$$

$$\Delta E = n\, C_V\, \Delta T$$

$$C_V = \frac{3}{2} R$$

$$\Delta T = 600k$$

$$n = \frac{P_A V_A}{R T_A} = 6.02\text{moles}$$

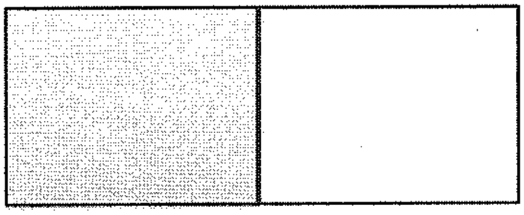
So $\Delta E = 4.5 \times 10^4\ J$

Thus: $Q = \Delta E - W$

$$= 7.5 \times 10^4\ J$$

We need to burn a volume $\frac{7.5 \times 10^4 J}{35\ MJ/L} = 2.1\ mL$

of gasoline per cycle.



Question 13 (4 points + possible bonus points):

A container with a partition in the middle has two sides with volume $1 m^3$. The container is filled on one side with a "gas" of 10^9 free electrons with temperature 300K. If the partition is removed so that the electrons fill the container, does the temperature increase, decrease, or stay the same? Explain. If you predict that the temperature will change, estimate the final temperature.

We have energy conserved.

The potential energy of the electrons is higher when they are closer together.

Thus, $\Delta U < 0$ when the gas expands.

So $\Delta K > 0$: the average kinetic energy of the electrons must increase.

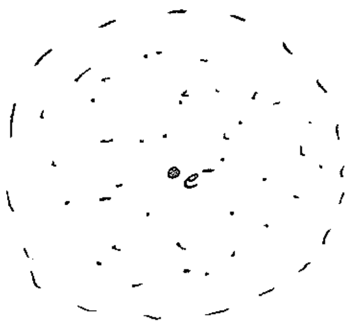
Thus, the temperature goes up.

Have: increase in T

$$= \frac{2}{3k_B} \times (\text{increase in avg K.E.})$$

$$= \frac{2}{3k_B} \times (\text{decrease in avg potential energy})$$

So we need to estimate the average potential energy per electron.



To simplify, imagine an electron in the middle of a spherical volume V, with a total of N electrons in this volume. The potential energy of this electron is

$$\mathcal{U} = \sum_{\substack{\text{other} \\ \text{electrons} \\ i}} \frac{ke^2}{r_i} \leftarrow \text{distance to middle.}$$

very crude estimate: - N terms in sum

- typical value of $\frac{1}{r}$ is $\frac{1}{V^{1/3}}$

$$\therefore \ \mathcal{U} \approx \frac{ke^2 N}{V^{1/3}}$$

better:

Contribution from shell of radius r, thickness dr:

$$n = \underbrace{(4\pi r^2 dr)}_{\text{volume}} \times \underbrace{\rho}_{\text{density}} \quad \text{electrons in shell}$$

$$\rho = \frac{N}{V}$$

$$\therefore \ \text{contribution is } \left(4\pi r^2 dr \times \frac{N}{V}\right) \times \frac{ke^2}{r}$$

Add up from $r=0$ to $r = \left(\frac{3}{4\pi} V\right)^{\frac{1}{3}}$ (i.e. radius of sphere)

$$\mathcal{U} = \int_0^{\left(\frac{3}{4\pi}V\right)^{\frac{1}{3}}} \frac{N}{V} 4\pi r^2 \frac{ke^2}{r} \, dr$$

$$= \frac{ke^2 N}{V^{1/3}} \cdot \frac{3^{2/3}}{2 \cdot (4\pi)^{\frac{1}{3}}}$$

almost the same as our crude estimate.

Rough estimate of ΔT is then

$$\frac{2}{3k_B} \left(ke^2 N\right) \left(\frac{1}{V_i^{1/3}} - \frac{1}{V_f^{1/3}}\right) \approx 10^5 \text{ K}$$