Solutions

Physics 161
Makeup Exam VAA
WEDNESDAY, APRIL 29, 2015

Directions: The exam consists of 25 multiple choice questions. Each question carries equal weight.

Useful equations and constants:

Note: 4 Answers not provided correctly: (see below) All students get these 4 questions for free.

(Take raw score and add ~~8 pts~~.) 24 pts

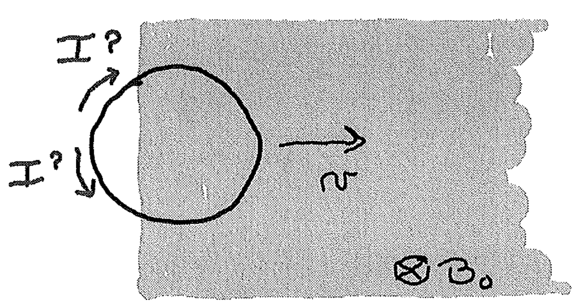
$$R = 8.314\,\frac{\text{J}}{\text{mole}\cdot\text{K}} = 0.082\frac{\text{ltr-atm}}{\text{mole}\cdot\text{K}}$$
$$1\text{ atm} = 1.01{\times}10^5\text{ Pa}$$
$$k = 1.38\times10^{-23}\,\frac{\text{J}}{\text{K}}$$
$$C_p = C_V + nR$$

$$T(^\circ\text{C}) + 273.15 = T(\text{K})$$
$$\Delta U = Q - W$$
$$dU = TdS - PdV$$
$$H = U + PV$$
$$dH = TdS + VdP$$
$$A = U - TS$$
$$G = H - TS$$
$$S = k\ln W;$$
$$W_{\text{monatomic gas}} = \left(T^{3/2}V\cdot\text{const.}\right)^N/N!$$
$$\tfrac{1}{2}m\left\langle v^2\right\rangle = \tfrac{3}{2}kT$$
$$\mu_0 = 4\pi\times10^{-7}\text{ Ns}^2/\text{C}^2$$
$$\epsilon_0 = 8.84\times10^{-12}\text{ C}^2/\text{Nm}^2$$
$$m_e = 9.1\times10^{-31}\text{ kg}$$
$$m_p = 1.67\times10^{-27}\text{ kg}$$
$$e = 1.6\times10^{-19}\text{C}$$
$$\vec{A}\times\vec{B} = \begin{vmatrix} \hat{x} & \hat{y} & \hat{z} \\ A_x & A_y & A_z \\ B_x & B_y & B_z \end{vmatrix}$$

(1-4pts) A circular wire loop lies in the plane of the page, as shown in the figure. A magnetic field B is directed into the page; the strength of the field, B_0, is nonzero everywhere in the shaded region. What happens as the loop slides to the right at a velocity v while straddling the region between $B = 0$ and $B = B_0$?

(a) A current is induced in the loop in the counter clockwise direction.
~~(b)~~ A current is induced in the loop in the clockwise direction.
(c) A current is not induced.

Current in wire produces field to prevent flux from increasing, so it produces a field that opposes the external field.



(2-4pts) According to Maxwell, electromagnetic waves propagate at a speed given by

(a) $(\epsilon_0\mu_0)^{1/2}$
(b) $(\epsilon_0\mu_0)^{-1/2}$

Two correct answers.

$$\frac{1}{\sqrt{\varepsilon_0\mu_0}} = \frac{1}{\sqrt{8.84\times10^{-12}\frac{C^2}{Nm^2}\cdot4\pi\times10^{-7}\frac{Ns^2}{C^2}}} = 3.00\times10^{8}\,\frac{m}{s}$$

Everyone was given credit for this problem, regardless of answer, because I couldn't think of a way to force the computer to accept (b) or (d)

(c) $(\epsilon_0/\mu_0)^{1/2}$
(d) $(\epsilon_0\mu_0)^{-1/2}$

(3-4pts) A straight segment of wire carrying current of 1 Ampere in the $\hat{\imath}$ direction is placed in a uniform magnetic field $\vec{B} = 2\text{T } \hat{\imath} + 1\text{T } \hat{\jmath} + 3\text{T } \hat{k}$. What is the force on the segment if it has a length of 1 meter?

(a) -1 N $\hat{\imath}$+2 N $\hat{\jmath}$+0 N $\hat{k}$
(b) 2 N $\hat{\imath}$+2 N $\hat{\jmath}$+1 N $\hat{k}$
(c) 0 N $\hat{\imath}-3$ N $\hat{\jmath}$+1 N $\hat{k}$
(d) -1 N $\hat{\imath}$+3 N $\hat{\jmath}$+1 N $\hat{k}$

$$\vec{F} = I\vec{l} \times \vec{B}$$

$$\begin{vmatrix} \hat{\imath} & \hat{\jmath} & \hat{k} \\ 1\text{Am} & 0 & 0 \\ 2\text{T} & 1\text{T} & 3\text{T} \end{vmatrix} = -\hat{\jmath}\,3\text{AmT} + \hat{k}\,1\text{AmT}$$

$$= -3\text{N}\hat{\jmath} + 1\text{N}\hat{k}$$

(4-4pts) Two infinitely long straight wires each carry a steady current. One wire carries a current of 1 Ampere in the $\hat{\imath}$ direction, and the other wire carries an unknown current in the $-\hat{\imath}$ direction. If the distance between the two wires is 8 meters, and the magnitude of the magnetic force between them, per meter of wire, is 1×10^{-7} N/m, what is the unknown current?

(a) 1 A.
(b) 2 A.
(c) 3 A.
(d) 4 A.

$1A = I_1$ $\quad I_2$ $\quad B_1$ $\quad 8m$

$B_1 = \frac{\mu_0 I_1}{2\pi r}$ $\quad 4\pi\times10^{-7}\,Tm/A$

$\frac{F_2}{l_2} = \frac{\mu_0 I_2 I_1}{2\pi r} = 1\times10^{-7}\frac{N}{m}$

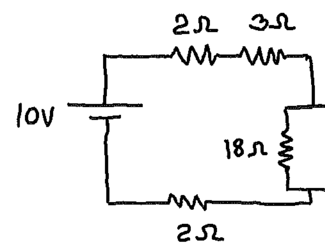
(5-4pts) Consider the circuit shown below, consisting of five resistors as marked, and a 10 V battery. At what rate is heat generated in the 3Ω resistor? (Assume that the battery has no internal resistance.)

(a) 1.8 W
(b) 1.6 W
(c) 1.4 W
(d) 1.2 W

$I_2 = \frac{1}{2}\,\frac{N}{m}\,\frac{\cancel{A}}{Tm}\,\frac{1.8m}{\cancel{1A}}$

$= 4\,A$

(if $Amp = \frac{N}{Tm}$)



$\frac{1}{R_{eq}} = \frac{1}{18} + \frac{1}{9} = \frac{3}{18}$ $\quad R_{eq} = 6\Omega$

$2\Omega + 3\Omega + 6\Omega + 2\Omega = 13\Omega$

$10V/13\Omega = 0.77A$

$(0.77A)^2\cdot 3\Omega$
$= I^2R = 1.77W$

≥

(6-4pts) A long hollow-core solenoid with length 1 meter has a diameter of 2 cm and a winding density of 5000 turns per ~~m~~ cm. What is the solenoid's self-inductance L?

FREE 4 pts (No Answer)

(a) 0.01 H.
(b) 0.1 H.
(c) 1 H.
(d) 10 H.

$L = \frac{\mu_0 N^2 A}{l} = \frac{4\pi\times10^{-7}\cdot(5\times10^5)^2\cdot\pi(0.01)^2}{1m} = 98.7\,H$

$L \cong 100\,H$

(7-4pts) The metal plates of a 0.50 μF parallel-plate capacitor are separated from one another by a dielectric material (insulator) with thickness 10. μm. If the dielectric constant is 3.0, what is the plate area?

(a) 0.11 m^2
(b) 0.15 m^2
(c) 0.19 m^2
(d) 0.25 m^2

$0.50\times10^{-6}\,F = \frac{3\varepsilon_0 A}{d} = \frac{3}{4\pi}\,\frac{1}{9\times10^9}\cdot\frac{A}{1\times10^{-5}m}$

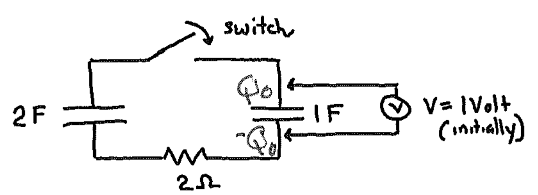
$\therefore A = \frac{4\pi}{3}\times(0.5)\times9\times10^9\times1\times10^{-5}\times10^{-6} = 0.188\,m^2$

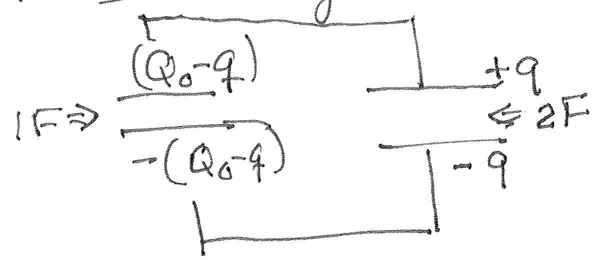
(8-4pts) Consider two capacitors connected in a closed-loop circuit as indicated in the figure. Initially the circuit is open, and the 2 F capacitor is uncharged but there is a 1 V drop across the 1 F capacitor. After the switch is closed and equilibrium has been reestablished, what is the voltage across each capacitor?

(a) 0.33 V
(b) 0.46 V
(c) 0.53 V
(d) 0.66 V

$Q_0 = CV_0 = 1F\cdot1V = 1C$ initially.

After:





(9-4pts) How much work must be performed to put 1 μC of charge on an 0.5 μF capacitor?

(a) 0.5 μJ
(b) 1.0 μJ
(c) 1.5 μJ
(d) 2.0 μJ

Voltage same: $\frac{Q_0 - q}{1F} = \frac{q}{2F}$

$\Delta U = \frac{Q^2}{2C} = \frac{(1\times10^{-6}C)^2}{2(0.5\times10^{-6}F)}$

$= 10^{-6}J$

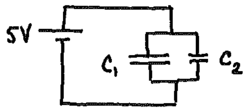
$\therefore \frac{3q}{2F} = \frac{Q_0}{1F}$ $\quad q = \frac{2}{3}Q_0$

$Q_0 - q = \frac{1}{3}Q_0$

$V = \frac{\frac{2}{3}Q_0}{2F} = \frac{1}{3}\,Volt$

(10-4pts) A 5 V battery is connected to two different capacitors placed in parallel in a closed loop circuit. How is the voltage divided between the two?

(a) Half the voltage is dropped across one capacitor and half the voltage is dropped across the other.
(b) The voltage across each capacitor is 5 V.
(c) The largest voltage drop is across the largest capacitor.
(d) The largest voltage drop is across the smallest capacitor.



(11-4pts) A wire has a resistivity of $1.0\times10^{-8}\Omega$m. What is the resistance for 100 meters of wire with a diameter of 2mm?

(a) 0.11 Ω
(b) 0.21 Ω
(c) 0.31 Ω
(d) 0.41 Ω

$R = \frac{\rho l}{A} = \frac{10^{-8}\Omega m \cdot 100\,m}{\pi (10^{-3} m)^2} = \frac{1}{\pi} 10^{-8+2+6} = \frac{1}{\pi} \times 10^0 = \frac{1}{3.14} \cong 0.31$

(12-4pts) A closed loop circuit consists of an 8.5 H inductor in series with an 0.01 μF capacitor. What is the natural frequency of oscillation (in radians per second) of the circuit?

(a) 3.4×10^1 s^{-1}
(b) 3.4×10^2 s^{-1}
(c) 3.4×10^3 s^{-1}
(d) 3.4×10^4 s^{-1}

$\omega_0 = \frac{1}{\sqrt{LC}} = \frac{1}{\sqrt{(8.5H)(10^{-8}F)}} = \frac{1}{\sqrt{8.5}} \times 10^4$

(13-4pts) A closed loop circuit consists of an 8.5 H inductor in series with a 2 Ω resistor. If initially the current is 1.0 Amps, how long must one wait for the current to decrease to 0.37 Amps?

(a) 2.10 ms
(b) 10.5 ms
(c) 1.15 s
(d) 4.25 s

$I = I_0 e^{-t/\tau}$

$\frac{I}{I_0} = \frac{0.37A}{1.0A} = e^{-t/\tau}$

$t = -\tau \cdot \ln(0.37) = -\frac{L}{R}\ln(0.37)$

(14-4pts) An electron moves in a uniform 2.0 nanotesla magnetic field. If its speed perpendicular to the field is 300 m/s, what is the radius of its orbit?

(a) 0.75 m
(b) 0.85 m
(c) 0.95 m
(d) 1.25 m

$\frac{mv^2}{r} = qvB$

$r = \frac{mv}{qB} = \frac{(9.1\times10^{-31} kg)(300 m/s)}{(1.6\times10^{-19})(2\times10^{-9} T)} = \underline{0.85\ m}$

(15-4pts) An electron enters a velocity selector of the type used by J. J. Thomson consisting of perpendicular B and E fields. What velocity will be selected (i.e. at what velocity will the total force on the electron be zero) if E=3×10^3 N/C and B=0.3 T?

(a) 1.0×10^4 m/s
(b) 1.0×10^5 m/s
(c) 1.0×10^6 m/s
(d) 1.0×10^7 m/s

$qE = qvB$

$v = \frac{E}{B} = \frac{3\times10^3 N/C}{0.3T} = 10^4 m/s$

(16-4pts) Who is the person who made the conjecture in 1856 that Ampere's law must be modified to account for the current associated with the displacement of invisible charged particles that fill all of free space?

(a) Faraday.
(b) Ampere.
(c) Maxwell.
(d) Oersted.

(17-4pts) What is the force between the electron and the proton in hydrogen at a separation of 0.0529 nm?

(a) 1.6 nN
No Answer (b) 1.4 nN
(c) 0.95 nN
4pts Free (d) 0.82 nN

$F = \frac{(1.6\times10^{-19}C)^2 \cdot (9\times10^9) Nm^2/C^2}{(3.29\times10^{-11} m)^2} = 8.2\times10^{-8} N$

(18-4pts) Consider a point just above the surface of a conductor where the charge density is $\sigma = -0.5$ nC/m^2. What is the magnitude of the electric field at this location?

(a) 31 N/C
(b) 48 N/C
(c) 57 N/C
(d) 64 N/C

$$E = \frac{\sigma}{\varepsilon_0} = -0.5\,nC/m^2 \cdot 4\pi \cdot 9\times10^9 = -56.5\ N/C$$

(19-4pts) A uniform magnetic field has a strength $\vec{B} = 2$ T $\hat{x}$+1 T $\hat{y}$. Consider a square loop of wire with a area vector $\vec{A} = 3$ m^2 $\hat{x}$ - 2 m^2 $\hat{y}$ having a resistance of 2 Ω. How much charge passes through the resistor when the field is turned off?

4 pts Free No Answer

(a) 0 Tm^2
(b) 1 Tm^2
(c) 4 Tm^2
(d) 5 Tm^2

Coulombs

$$\vec{B}\cdot\vec{A} = 6-2 = 4\,Tm^2$$

$$-\frac{d\Phi}{\cancel{dt}} = IR = \frac{dQ}{\cancel{dt}} \cdot 2\Omega$$

$$\Delta Q = -\frac{1}{2\Omega}(\Delta\Phi)$$

$$\Delta\Phi = -4\,Tm^2$$

$$\Delta Q = -2\left(\frac{Tm^2}{\Omega}\right) = -2 \text{ coulombs.}$$

(20-4pts) Consider a process in which a fluid expands spontaneously at constant T. If $\Delta U = 200$ J, and $\Delta S = 90000$ J/K, for what is the maximum amount of work that could be extracted during the expansion were one so inclined to extract it at 300 K?

4pts FREE No Answer

(a) 100 J
(b) 200 J
(c) 300 J
(d) 400 J

$\Delta A = \Delta U - \Delta(TS) = \Delta U - T\Delta S = 200\text{ J} - (300\text{K})\, 9\times10^4 \frac{\text{J}}{\text{K}}$

$= \ldots$ X

$W_{max} = -\Delta A$

(21-4pts) An ideal gas is expanded isothermally, from $P = 2$ atm and $V = 1$ liter, to $P = 1$ atm and $V = 2$ liters. The expansion may or may not have been carried out reversibly. Circle the statement which is certainly true:

(a) the work performed on the surroundings is smaller than $2\ln 2$ liter-atm.
(b) the heat added to the gas from the surroundings is greater than $2\ln 2$ liter-atm.
(c) $\Delta U < 0$.
(d) $\Delta S_{\text{surroundings}} > 0$.

$W_{rev} = nRT\ln(2) = 2\ln 2$

A student complained that I should have said work was less than or equal to 2*ln(2) because the expansion could have been reversible (see statement of problem). He said that this caused him to shop for other answers besides (a). A valid point!! - I have no choice but to thrown this problem out - bad for your teachers morale (but good for students).

(22-4pts) The working fluid in a heat engine undergoes a cyclic process, repeatedly returning to its initial state. This means that over each cycle, the change

(a) $\Delta U = 0$.
(b) $\Delta S > 0$.
(c) $\Delta H < 0$.
(d) $\Delta P > 0$

(23-4pts) If 600 kJ of heat is transferred to a system that is in contact with the surroundings at 300 K, the change in entropy of the surroundings is

(a) -2 kJ/K
(b) 2 kJ/K
(c) -18 kJ/K
(d) 18 kJ/K

$\Delta S_{surr} = \frac{-600\text{kJ}}{300\text{K}} = -2\frac{\text{kJ}}{\text{K}}$

(24-4pts) Two glass bulbs having the same volume are connected to one another by a stopcock. Initially, one bulb is filled with helium gas at 1 atm, and the other bulb is filled with xenon gas at 1 atm. The bulbs are in thermal contact with the surroundings at 298 K. When the stopcock is opened, the gases mix. Assuming ideal gas behavior, which of the following statements is true?

(a) $\Delta U < 0$
(b) $\Delta S_{\text{surroundings}} > 0$
(c) $\Delta S_{\text{universe}} > 0$
(d) $Q > 0$

(25-4pts) The equation $S = k\ln W$ is engraved on Boltzmann's tombstone in Vienna. What is W?

(a) Boltzmann's middle initial.
(b) The gas constant divided by 6.02×10^{23}.
(c) The number of microscopic configurations a system may have while still being considered to be in the same macroscopic equilibrium state.
(d) Boltzmann's middle initial.