Solutions
V. AA

Physics 161
Final Exam
FRIDAY, MAY 13, 2016

Directions: The exam consists of 25 multiple choice questions and 2 bonus questions. Each is worth 4 pts.

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

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

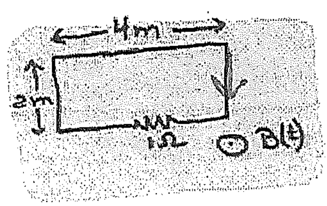
(1) Consider a *long* solenoid with length 20 cm and radius 0.5 cm. The number of windings is 1000. If the permeability of the core is $\mu_0 = 4\pi\times10^{-7}$ T·m/A, what is the current if the magnetic field strength $B = 6.3$ mT within the solenoid (away from the ends)?

(a) 1.0 A
(b) 1.2 A
(c) 1.4 A
(d) 1.6 A
(e) 1.8 A

$B = \mu_0 n I$,
$I = \frac{6.3\times10^{-3}\text{ T }(0.20\text{ m})}{4\pi\times10^{-7}\cdot1000} = 1.0\text{ A}$

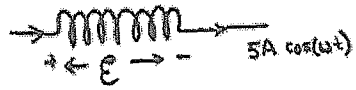
(2) A rectangular loop of wire with dimensions 2 m × 4 m and having resistance 1.0 Ω lies in the plane of the page, as shown in the figure. A uniform magnetic field directed out of the page is increasing in strength at a rate of 1.0 T per second. What is the induced current for the configuration shown? (The loop's self inductance is negligible.)

(a) A 4 Amp current is induced in the clockwise direction.
(b) A 4 Amp current is induced the counterclockwise direction.
(c) An 8 Amp current is induced in the clockwise direction.
(d) An 8 Amp current is induced in the counterclockwise direction
(e) A 12 Amp current is induced in the clockwise direction.



$\mathcal{E} = -\frac{d}{dt}(BA) = -\frac{dB}{dt}\cdot A$
$= -(1\text{ T/s})\cdot 8\text{ m}^2 = -8\text{ volts}$
$I = \frac{\mathcal{E}}{R} = \frac{-8\text{ V}}{1\Omega} = -8\text{ A}$

(3) A 20 mH inductor is placed in an AC circuit.



If the current in the inductor is sinusoidal, such that $I = 5\text{A} \cos(\omega t)$ where t is in seconds, and the maximum emf across the inductor is 38 V, what is the frequency ω?

(a) 260 rad/sec.
(b) 450 rad/sec.
(c) 380 rad/sec.
(d) 220 rad/sec.
(e) 110 rad/sec.

$\mathcal{E} = L \frac{dI}{dt} = -(L \cdot 5A \cdot \omega) \sin(\omega t)$

$38 \text{ Volts} = (20 \times 10^{-3}) \cdot 5 \cdot \omega$

$\omega = 380 \text{ rad/s.}$

(4) A generator coil rotates at the rate of 60 Hz (cycles per second) in a uniform magnetic field of 0.1 T. The coil has an area of 0.10 m^2 and is wound with N turns of wire. If the amplitude of the emf that is generated is 730 V, what is N?

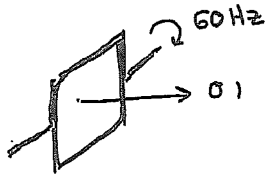
(a) 104
(b) 121
(c) 146
(d) 165
(e) 194

$\Phi = NBA \cos(\omega t)$

$-\frac{d\Phi}{dt} = NBA\omega \sin(\omega t)$

$730 \text{ Volts} = N \cdot (0.1T) \cdot (0.1 m^2) \cdot 120\pi$

$N = 194$



(5) Which of the following was the theoretical contribution of J. C. Maxwell in 1856?

(a) He postulated that Gauss's law should be modified by the addition of a term that describes the generation of a magnetic field due to the current associated with the displacement of massless charged particles that fill all space.

(b) He postulated that Faraday's law should be modified by the addition of a term that describes the generation of a magnetic field due to the current associated with the displacement of massless charged particles that fill all space.

(c) He postulated that Coulomb's law should be modified by the addition of a term that describes the generation of a magnetic field due to the current associated with the displacement of massless charged particles that fill all space.

(d) He postulated that Ampere's law should be modified by the addition of a term that describes the generation of a magnetic field due to the current associated with the displacement of massless charged particles that fill all space.

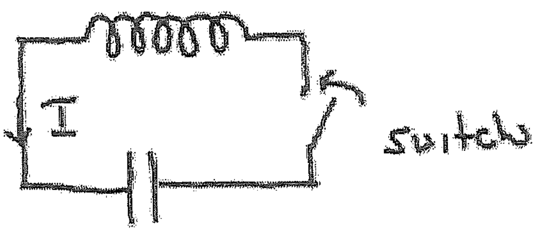
(6) What are the units of $(\epsilon_0 \mu_0)^{-1/2}$?

(a) meters/sec
(b) Newtons
(c) Joules
(d) Coulombs/sec
(e) Tesla/sec

(7) A 0.5 mH inductor is placed in series with a 0.5 μF capacitor in a closed-loop circuit with negligable resistance. If the capacitor is initially charged, what will be the frequency at which the current I oscillates when the switch is closed?

$$\omega = \frac{1}{\sqrt{LC}} = \frac{1}{\sqrt{(0.5 \times 10^{-3})(0.5 \times 10^{-6})}}$$

$= 6.32 \times 10^4 \frac{\text{rad}}{\text{sec}}$ $\quad f = \frac{1 \text{ cycle}}{2\pi \text{ rad}} \cdot 6.32 \times 10^4 = 10 \text{ kHz}$



(a) 6.0 kHz.
(b) 8.0 kHz.
(c) 10. kHz.
(d) 12. kHz.
(e) 14. kHz.

(8) A *long* hollow-core solenoid has a diameter of 2 cm and consists of 5000 turns of wire uniformly wound over a length ℓ. If the solenoid's self-inductance is 5 mH, what is ℓ?
(a) 1.5 m
(b) 2.0 m
(c) 2.5 m
(d) 3.0 m
(e) 3.5 m

$L = \frac{\mu_0 N^2 A}{\ell}$ $\ell = \frac{4\pi \times 10^{-7} \cdot (5000)^2 \cdot \pi (0.01)^2}{(5 \times 10^{-3})} = 1.97$ m

(9) A long thin wire carries a current I. If the strength of the magnetic field 1 meter away from the wire is 6×10^{-7} T, what is I?
(a) 3.0 A
(b) 2.5 A
(c) 2.0 A
(d) 1.5 A
(e) 1.0 A

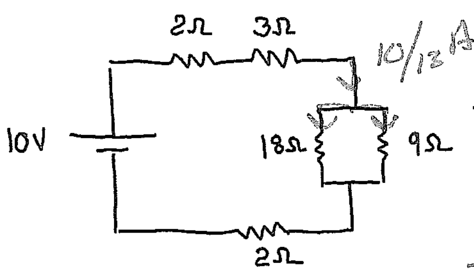
$B = \frac{\mu_0 I}{2\pi r}$ $I = \frac{2\pi (1\,m)(6\times10^{-7}\,T)}{2(4\pi\times10^{-7})} = 3$ A

(10) Consider the circuit shown below, consisting of five resistors as marked, and a 10 V battery. What is the power dissipated in the 9Ω resistor? (Assume that the battery has no internal resistance.)
(a) 1.6 W
(b) 1.8 W
(c) 2.1 W
(d) 2.4 W
(e) 2.7 W

$I = \frac{10V}{13\Omega} = \frac{10}{13}$ A

$\frac{10}{13} \cdot \frac{\left(\frac{1}{9}\right)}{\left(\frac{1}{9}+\frac{1}{18}\right)} = \frac{2}{3}\left(\frac{10}{13}\right) = 0.513$ A

$P = (0.513)^2 \cdot 9 = 2.37$ W



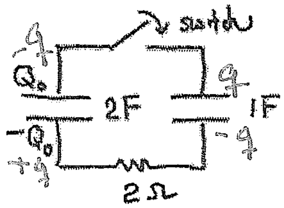
$\frac{1}{R_{eq}} = \frac{1}{18} + \frac{1}{9} = \frac{3}{18}$

$R_{eq} = \frac{18}{3} = 6\Omega$

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

(11) Consider the energy stored by two capacitors connected in a closed-loop circuit as indicated in the figure. Initially the circuit is open, and the 1 F capacitor is uncharged while the 2 F capacitor has a charge $Q_0 = 2$ C. This gives the system an initial energy of 1.0 Joules. When the switch is closed, charge flows spontaneously from the 2 F capacitor to the 1 F capacitor until equilibrium is established. What is the final energy?
(a) 0.33 J
(b) 0.67 J

(c) 1.0 J
(d) 1.33 J
(e) 1.67 J



(12) If 4.25 J is the minimum work required to establish a current I in an 8.5 H inductor. What is I?
(a) 1.0 A.
(b) 1.25 A.
(c) 1.50 A.
(d) 1.75 A.
(e) 2.0 A.

(13) If 1.25 J is the minimum amount of work required to charge up a capacitor to a potential of 1.0 V, what is its capacitance?
(a) 2.0 F.
(b) 2.25 F.
(c) 2.5 F.
(d) 2.75 F.
(e) 3.0 F.

(14) The electric field just above a point on a conducting surface is 23 N/C. What is the charge density on the surface at this point?
(a) 0.100 nC/m^2
(b) 0.125 nC/m^2
(c) 0.150 nC/m^2
(d) 0.175 nC/m^2
(e) 0.200 nC/m^2

(15) An electron moves in a uniform 4.0 nano Tesla magnetic field. What is the period of its circular orbit?
(a) 0.009 s
(b) 0.018 s
(c) 0.025 s
(d) 0.034 s
(e) 0.039 s

(16) A sphere with radius 1 m carries a uniform surface charge of 1.5 μC. What is the magnitude of the electric field at a point 0.5 m from the center of the sphere?
(a) 54 kV/m
(b) 27 kV/m
(c) 13 kV/m
(d) 6 kV/m
(e) 0 kV/m

(17) An electron and a proton are separated from one another by a distance of 0.050 nm. What is the force of attraction between them?
(a) 62 nN
(b) 72 nN
(c) 78 nN
(d) 86 nN
(e) 92 nN

(18) Who is credited with the discovery that an electric field can be produced by changing magnetic flux?

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

(19) Consider a process in which a fluid is compressed spontaneously at a constant temperature of 300 K. If $\Delta U = -400$ J, and $\Delta S = -1$ J/K, what is the maximum amount of work that could be extracted during the expansion if one were so inclined?

(a) 100 J
(b) 200 J
(c) 300 J
(d) 400 J
(e) 500 J

$\Delta A = \Delta U - T\Delta S = -400\,J + 300\,J = -100\,J$

$W_{max} = -\Delta A = 100\,J$

(20) An ideal gas initially at $P = 2$ atm and $V = 1$ liter expands isothermally against a constant pressure of 1 atm, to a final pressure of 1 atm. What is Q for this expansion?

(a) 2.0 liter-atm
(b) $2.0 \ln(2.0)$ liter-atm
(c) 1.0 liter-atm
(d) 0.75 liter-atm
(e) 0.50 liter-atm

$\Delta U = Q - W = 0$ for ideal gas at const. T.

$\therefore Q = W = P_{ext}(V_2 - V_1) = P_{ext}\left(\frac{nRT}{P_{ext}} - \frac{nRT}{P_1}\right) = nRT\left(1 - \frac{P_{ext}}{P_1}\right) = 2\,l\text{-atm}\left(1 - \frac{1}{2}\right) = 1\,l\text{-atm}$

(21) What is the change in entropy for one mole of monatomic ideal gas whose temperature decreases by a factor of 5 while the volume remains the same?

(a) 4.8 J/K
(b) 3.6 J/K
(c) −2.4 J/K
(d) −3.8 J/K
(e) −5.5 J/K

$dU = TdS - PdV$ ($dV \to 0$)

$= \frac{3}{2} nR\, dT$

$\therefore dS = \frac{3}{2} nR \frac{dT}{T}$

$\Delta S = \frac{3}{2} nR \ln(T_2/T_1) = -\frac{3}{2} nR \ln(5) = -20\ \text{J/K}$

(22) Two identical glass bulbs are connected to one another by a stopcock and in contact with the surroundings at 294 K. The first bulb is filled with 10 moles of helium gas at 1 atm, and the second bulb is evacuated. When the stopcock is opened, the gas expands to fill both bulbs. Assuming ideal gas behavior, what is the maximum work that could be extracted from the isothermal process were one so inclined?

(a) 15 kJ
(b) 17 kJ
(c) 21 kJ
(d) 25 kJ
(e) 29 kJ

$\Delta S = nR\ln(2) = (10)(8.314)\ln(2)$

$\Delta A = \Delta U - T\Delta S = -(294)(10)(8.314)\ln(2)$

$W_{max} = -\Delta A = 16.9 \times 10^3 \Rightarrow 17\ \text{kJ}$

(23) The first law of thermodynamics is a postulate that

(a) *entropy* is a state function, and the *energy* of the universe is constant.
(b) *entropy* is a state function, and the *entropy* of the universe always increases.
(c) *energy* is a state function, and the *energy* of the universe proceeds to a minimum.
(d) energy is a state function, and the energy of the universe remains constant.
(e) enthalpy is a state function, and the enthalpy of the universe remains constant.

(24) When the working fluid is an ideal gas, a (hypothetical) reversible heat engine operating between a hot reservoir at T_H and a cold reservoir at T_C has an efficiency $(T_H - T_C)/T_H$, where temperature is in Kelvin. When a non-ideal gas is substituted as the working fluid, which of the following will be true?

(a) The reversible heat engine will have an efficiency that *is lower* than $(T_H - T_C)/T_H$.
(b) The reversible heat engine will have an efficiency that *is higher* than $(T_H - T_C)/T_H$.
(c) The reversible heat engine will have an efficiency that *is the same* as its efficiency with an ideal gas.
(d) The reversible heat engine will transfer more heat into the cold reservior while performing the same amount of work.
(e) The reversible heat engine will absorb more heat from the hot reservior while performing the same amount of work.

(25) When a certain fluid with is heated at *constant volume*, its temperature increases from 300 K to 400 K. If the heat capacity at constant volume is a constant 20 J/K over this temperature range, which of the following *must* be true?

(a) $\Delta U = 2$ kJ
(b) $\Delta H = 2$ kJ
(c) $\Delta S = -5.8$ J/K
(d) $\Delta A = -4$ kJ
(e) $W = 2$ kJ

$\Delta U = C_V \Delta T = 20\frac{J}{K}(400-300) = 2\,kJ$

(26: **Bonus 1**) A monatomic ideal gas initially at 2.00 atm and 300 K is compressed adiabatically by a constant pressure of 7.00 atm, to a final pressure of 7.00 atm. What is the final temperature of the gas?

(a) 200 K
(b) 300 K
(c) 400 K
(d) 500 K
(e) 600 K

$\frac{3}{2} nR(T_2 - T_1) = -P_{ext}\left(\frac{nRT_2}{P_{ext}} - \frac{nRT_1}{P_1}\right)$ $\quad T_2 = \frac{10/2}{5/2} T_1$

$T_2\left(\frac{3}{2}+1\right) = T_1\left(\frac{P_{ext}}{P_1} + \frac{3}{2}\right) = T_1\left(\frac{7}{2}+\frac{3}{2}\right)$ $\quad = 2T_1$

(27: **Bonus 2**) The globe of the Regener Hall van de Graff generator has a radius of 15 cm. In dry air, it can be charged until the maximum field reaches the breakdown threshold of 3×10^6 N/C. What is the minimum amount of work required to put this much charge on it? (Treat the globe is though an isolated metal sphere.)

(a) 0.50 J
(b) 0.75 J
(c) 1.30 J
(d) 1.69 J
(e) 1.91 J

$\Delta U = \frac{Q^2}{2C}$ $\quad C = 4\pi\varepsilon_0 R$ for isolated spheres!

Now, $\frac{Q}{4\pi\varepsilon_0 R^2} = E_{Threshold}$

$\therefore \quad \Delta U = \frac{E_T^2 (4\pi\varepsilon_0 R^2)^2}{2 \cdot 4\pi\varepsilon_0 R}$

$= E_T^2 \cdot 2\pi\varepsilon_0 R^3$

$= \frac{(3\times10^6 N/C)^2}{2} \cdot \frac{1}{(9\times10^9)} \cdot (0.15)^3$

$= 1.69$ J

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