Physics 1B: Electricity & Magnetism, Fall 2010
Final Exam, Dec. 9, 2010

This is version **A**!

Useful coefficients: $g = 9.8$ m s^{-2}; Unit of elementary charge $e = 1.6 \times 10^{-19}$ C
Mass of proton, m_p = Mass of neutron, $m_n = 1.67 \times 10^{-27}$ kg
Mass of electron, $m_e = 9.11 \times 10^{-31}$ kg
Coulomb's constant, $k_e = 8.99 \times 10^9$ N m^2 C^{-2}
Permittivity of free space $\epsilon_0 = \frac{1}{4\pi k_e} = 8.85 \times 10^{-12}$ C^2 N^{-1} m^{-2}
1 eV = 1.6 $\times 10^{-19}$ J
1 T = 10^4 G
Permeability of free space $\mu_o = 4\pi \times 10^{-7}$ T m A^{-1}
Prefixes: milli (m) = 10^{-3}; micro (μ) = 10^{-6}; nano (n) = 10^{-9}; pico (p) = 10^{-12}; fempto (f) = 10^{-15}

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A1/B2/C4: An electron and a proton are placed in the same uniform electric field. They begin to accelerate in opposite directions. The ratio of the magnitude of the acceleration of the electron to that of the proton is approximately
a. 1830/1
b. 1/1830
c. 1.0/1.6
d. 1.6/1.0
e. 500/1

ANSWER: The magnitude of the electrostatic force will be the same for each particle: F = qE = (1e)(E).
Using F=ma, and just considering magnitudes of vectors, we have
F(electron) = $m_e a_e$ = F(proton) = $m_p a_p$
$\frac{a_e}{a_p} = \frac{m_p}{m_e} = \frac{1.67\times10^{-27}kg}{9.11\times10^{-31}kg} = \mathbf{1830/1}$.

A2/B5/C1: Two identical balls have the same mass and the amount of charge, but the charge on ball A is positive and the charge on ball B is negative. The balls are placed on a smooth, level, frictionless table whose top is an insulator. Which of the following is true?
a. Since the force on A is equal but opposite to the force on B, they will not move.
b. They will move together with constant acceleration.
c. Since the force on both balls is negative they will move in the negative direction.
d. Since the forces are opposite in direction, the balls will move away from each other.
e. None of the above is correct.

SOLUTION: This was virtually a repeat of a question from quiz 1. The two balls will start moving towards each other, but their acceleration will NOT be constant. The acceleration a of each ball is related to the magnitude of the electrostatic force F_e at any given instant via $F_e = ma$, but F_e at any given instant depends on the distance of separation r of the two balls, which is decreasing as the balls roll towards each other. So as r decreases, the magnitude of F_e increases, and the instantaneous acceleration will also be increasing (not constant, so choice "b" is incorrect). So the answer is **"none of the above."**

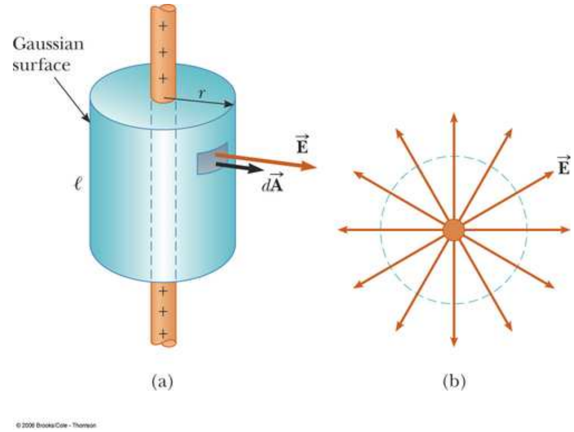
A3/B1/C2: Which of the following characteristics are held in common by both gravitational and electrostatic forces when dealing with either point masses or charges?
a. inverse square distance law applies
b. forces are conservative
c. potential energy is a function of distance of separation
d. all of the above choices are valid

Solution: **d.**

A4/B3/C5: In the core of a supergiant star, nuclear fusion is occurring: in one fusion reaction, three helium nuclei (^{4}He; 2 protons, 2 neutrons each) fuse together to form a single carbon nucleus (^{12}C; six protons and six neutrons in each). Suppose three ^{4}He nuclei have just fused to create a ^{12}C nucleus, and there's an extra ^{4}He nucleus sitting 4 nm away (1 nm $= 10^{-9}$ m). What is the resulting electrostatic force between the ^{12}C and ^{4}He nuclei? (Note: temperatures here are high enough that all atoms are ionized, i.e., all electrons have been stripped, so assume electrons are not relevant here.)
a. 1.8×10^{-8} N
b. 9.6×10^{-8} N
c. 3.0×10^{-11} N
d. 9.6×10^{-10} N
e. 1.7×10^{-10} N

Solution: $q_1 = +6$e; $q_2 = +2$e.
$F_e = \frac{k_e q_1 q_2}{r^2} = (8.99 \times 10^9 Nm^2C^{-2})(2)(6)((1.6 \times 10^{-19}C)^2)/(4 \times 10^{-9}m)^2) =$
1.7×10^{-10} N

A5/B4/C3: An infinite line of charge has a linear charge density λ of $+1\times10^{-8}$ C/m. Consider an 8.85 cm section of this line, surrounded by a cylindrical Gaussian surface as shown. What is the total electric flux Φ_E in Nm^2/C exiting this surface?



a. $1/(4\pi)$ Nm^2/C
b. 4π Nm^2/C
c. 100 Nm^2/C
d. 1 Nm^2/C
e. 8.85 Nm^2/C

ANSWER: Gauss' Law is $\Phi_E = Q_{encl}/\epsilon_0$, where Q_{encl} is the total charge enclosed by the Gaussian surface: $Q_{encl} = (\lambda)(8.85\text{cm}) = (1\times10^{-8}\ \text{C/m})(8.85\times10^{-2}\text{m}) = 8.85\times10^{-10}\text{C}$.
So $\Phi_E = (8.85 \times 10^{-10} C)/8.85 \times 10^{-12}\ \text{C}^2\ \text{N}^{-1}\ \text{m}^{-2} =$ **100 Nm^2/C.**

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A6/B8/C7: In which case does an electric field do a positive quantity of work on a charged particle?
a. a negative charge moves opposite to the direction of the electric field.
b. a positive charge is moved from a point of low potential energy to a point of higher potential energy.
c. a positive charge completes one circular path around a stationary positive charge.
d. a positive charge completes one elliptical path around a stationary positive charge.

Solution: In order to make choices b, c, or d happen, an external agent would have to supply some work at some point.
For choice b, for example, the positive charge is moving against electric fields lines, and moving away from negative charge and towards positive charge. That is, the charge must not be moving "voluntarily," meaning that for this to happen, the work must be provided by an external agent and not by the electric field (E-field tries to move the positive charge towards the negative, with E-field lines, but fails to do so; the E-field thus does a negative quantity of work).
For choice a, the E-field does all the work in moving the negative charge.

A7/B7/C10: A region of space has a electric field quantified by V(x) = $4x + 7$. What is E(x)?
NOTE: As discussed during the final exam, this problem should have read "A region of space has an electric potential quantified by V(x) = $4x$ + 7. What is E(x)?" and all the responses should have had negative signs in front of them (as

added here:)
a. –7
b. $-(2x^2 + 7x)$
c. $-4x$
d. –4
e. 0

ANSWER: $E(x) = -dV(x)/dx =$ **–4.**

A8/B12/C11: Five identical capacitors are connected in series to a 9-Volt battery and charged (neglect resistance in the wires; neglect internal resistance in the battery). The charge on each capacitor is 4μC. Calculate the capacitance of each individual capacitor.
a. 11.1μF
b. 2.22μF
c. 0.44μF
d. 88 nF.
e. 4.4 nF.

ANSWER: For capacitors connected in series, we find the equivalent capacitance C_{eq} via
$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + ...$
For five identical capacitors, each with indiv. capacitance C,
$\frac{1}{C_{eq}} = \frac{1}{C} + \frac{1}{C} + \frac{1}{C} + \frac{1}{C} + \frac{1}{C} = \frac{5}{C}$

C_{eq} is also equal to Q/ϵ, where the charge on any one capacitor is also equal to the charge on the equivalent capacitor (valid for capacitors connected in series only).
$C_{eq} = 4\mu\text{C}/9\text{V} = 4.44\times10^{-7}$ F.
$C_{eq} = C/5$
$C = 5\ C_{eq} = 2.22\times10^{-6}\text{F} =$ **2.22μF.**

A9/B6/C6: A particle with positive charge Q_1 is placed at coordinates $(+a,+a)$ and a second particle with negative charge Q_2 is placed at coordinates $(+a,-a)$. The absolute potential at the origin is then measured to be V_{init}. Then, a third particle with positive charge Q_1 is added at coordinates $(-a,-a)$, and a fourth particle with negative charge Q_2 is added at coordinates $(-a,+a)$. What is the final value of the absolute potential at the origin?
a. 0
b. V_{init}
c. $2V_{\text{init}}$
d. aV_{init}
e. $4V_{\text{init}}$

ANSWER: When the first two particles are placed, the potential at the origin is
$V_{\text{init}} = V_1 + V_2 = \frac{k_e Q_1}{\sqrt{2}a} + \frac{k_e Q_2}{\sqrt{2}a}$ (V will be positive or negative depending on whether the

magnitude of Q_1 is greater or less than that of Q_2, respectively.
The total potential at a point in space due to a number of discrete point charges is equal to the sum of the potentials from each charge.
The 3rd and 4th charges are the same charge and distance from the origin as the 1st and 2nd charges, respectively, so they offer the same potential as that from the sum of the 1st + 2nd charges.
When the 3rd and 4th particles are added, the total V is then
$V_{\text{final}} = V_1 + V_2 + V_3 + V_4 = \frac{k_e Q_1}{\sqrt{2}a} + \frac{k_e Q_2}{\sqrt{2}a} + \frac{k_e Q_1}{\sqrt{2}a} + \frac{k_e Q_2}{\sqrt{2}a} = 2\frac{k_e Q_1}{\sqrt{2}a} + 2\frac{k_e Q_2}{\sqrt{2}a} = 2V_{\text{init}}$.

A10/B11/C9: The absolute potential at a point in space due to the electric fields present is 5.0 V. How much work must one do to bring a +0.8 C charge from infinity to that point?
a. 5 J
b. 4 J
c. 6.3 J
d. 0.8 J
e. 20 J

ANSWER: ΔU = qΔV
At infinity, V and U are defined to be zero.
ΔU = (+0.8C)(5V) = **4 J.**

A11/B10/C12: Two capacitors are connected in parallel with a battery: capacitor A has capacitance C_A; capacitor B has capacitance C_B; C_A is greater than C_B. Which of the following statements is true?
a. There is the same quantity of charge stored on each capacitor.
b. There is a larger potential difference across capacitor A.
c. There is a larger potential difference across capacitor B.
d. There is more charge stored on capacitor B.
e. There exists the same potential difference across both capacitors.

ANSWER: This is a direct repeat from quiz 3: For circuit elements connected in parallel with a battery, the voltage drop across them must be identical (**confirming choice E** and ruling out choices B & C). Because the values of capacitance are not equal, and using C = Q/ΔV, there must be differing amounts of charge stored on each capacitor (ruling out A). Finally, because $C_A > C_B$, and because Q = CΔV, we have $Q_A > Q_B$ (in contradiction to choice D).

A12/B9/C8: An proton is moving with a constant velocity 2.77×10^5 m/s. It then enters a region where, thanks to a uniform electric field oriented anti-parallel to the velocity, it experiences deceleration through a potential difference of –200 V. What is the proton's final velocity?
a. 1.96×10^5 m/s
b. 3.92×10^5 m/s
c. 4.77×10^5 m/s
d. 0.77×10^5 m/s

ANSWER: The proton initially has a kinetic energy of $K_{\rm init} = \frac{1}{2}m_p v_{\rm init}^2 = 6.4 \times 10^{-17}$ J = 400 eV.
The potential energy LOST during the deceleration can be calculated as $\Delta U = q\Delta V = (1.6 \times10^{-19}\mathrm{C})(–200\mathrm{V})$ = –3.2 $\times10^{-17}$J = –200 eV. This potential energy is the amount of work the electric field does in slowing down the proton.
The final kinetic energy $K_{\rm final} = K_{\rm init} + \Delta U = 6.4 \times 10^{-17}$ J – 3.2 $\times10^{-17}$J = 3.2 $\times 10^{-17}$
(Or, $K_{\rm final}$ = 400 eV – 200 eV = 200 eV, but you have to convert back to Joules to solve for the final velocity).

$K_{\rm final} = \frac{1}{2}m_p v_{\rm final}^2$
$v_{\rm final} = \sqrt{2K_{\rm final}/m_p} = \mathbf{1.96}\times10^5$ **m/s**
Note that since the proton's final kinetic energy is $\frac{1}{2}$ times the initial kinetic energy, the final velocity is $\frac{1}{\sqrt{2}}$ times the initial velocity.

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A13/B16/C15. Four identical resistors, each with a resistance of 12Ω, are connected in parallel with a 12-Volt battery. What is the current through any one resistor?
a. 0.5 A
b. 1.0 A
c. 2.0 A
d. 4.0 A
e. 8.0 A

ANSWER: The equivalent resistance $R_{\rm eq}$ can be calculated via
$\frac{1}{R_{\rm eq}} = \frac{1}{12\Omega} + \frac{1}{12\Omega} + \frac{1}{12\Omega} + \frac{1}{12\Omega} = \frac{4}{12\Omega} = \frac{1}{3\Omega}$
$R_{\rm eq} = 3\Omega$.
Let's call the total current flowing through the battery or through the equivalent resistor $I_{\rm tot}$.
Since the equivalent resistance satisfies $\epsilon = I_{\rm tot}R_{\rm eq}$, $I_{\rm tot} = \epsilon/R_{\rm eq}$ = 12V / 3Ω = 4A.

Going back to the original circuit, where the total current $I_{\rm tot}$ will be split up in the four parallel branches according to $I_{\rm tot} = I_1 + I_2 + I_3 + I_4$. However, because each of the four resistors is identical (same R and same ΔV across each), I_1, I_2, I_3, and I_4 will be identical, and each will thus be equal to $I_{\rm tot}/4 =$ **1.0 A.**

Note: Grigor offers a much more simple, straightforward solution to this problem: Because the resistors are all in parallel, ΔV across any one resistors will be 12V. The current through any one resistor is thus $I = \epsilon/R =$ **1 A.**

A14/B17/C18: A 25Ω resistor, 25 mF parallel-plate capacitor, and 25-Volt battery are all connected in series with a switch. At time $t = 0$, the switch is closed, and charge begins to accumulate on the capacitor. What is the voltage difference between the plates of the capacitor at a time $t = 1.5$ seconds?
a. 0.1 V
b. 22.7 V
c. 9.2 V
d. 15.8 V
e. 24.9 V

ANSWER: The time constant $\tau = RC = (25\Omega)(25\times10^{-3}\mathrm{F}) = 0.625$ seconds = 625 msec. When charge is accumulating on the capacitor, the voltage difference across the capacitor plates ΔV_C will initially be zero, but rise up towards its maximum, value, $\epsilon = 25$ V.
$\Delta V_\mathrm{C} = \epsilon\ (1 - e^{-t/\tau})$
At a time $t = 1.5$ seconds,
$\Delta V_\mathrm{C} = \epsilon\ (1 - e^{-1.5s/0.625s})$
$\Delta V_\mathrm{C} = \epsilon\ (1 - e^{-2.4})$
$\Delta V_\mathrm{C} = \epsilon\ (1 - 0.091)$
$\Delta V_\mathrm{C} = \epsilon\ (0.909)$
$\Delta V_\mathrm{C} = (25\mathrm{V})(0.909)$
$\Delta V_\mathrm{C} = \mathbf{22.7\ V.}$
That is, at 2.4 time constants, ΔV_C has reached 90.9% of its maximum value.

A15/B14/C17: If the current in a wire is tripled, what effect does this have on the electron drift velocity in the wire?
a. It stays the same.
b. It triples.
c. It decreases by a factor of three.
d. It increases by a factor of nine.

Answer: Drift velocity and current are linearly proportional to each other, so if you triple one, you triple the other (assuming that the wire's cross sectional area, composition, etc. do not change)

A16/B18/C13: A 9.0-volt battery moves 100 milliCoulombs of charge through a circuit connecting the battery's terminals. How much energy was delivered to the circuit?

a. 90.0 J
b. 9.0 J
c. 0.9 J
d. 3.0 J
e. 0.3 J

Answer: The energy can calculated via Work $= q\Delta V = (0.1\text{ C})(9.0\text{ V}) = \mathbf{0.9\ J.}$ This is the amount of work the battery has done to move charge into/out of the circuit.

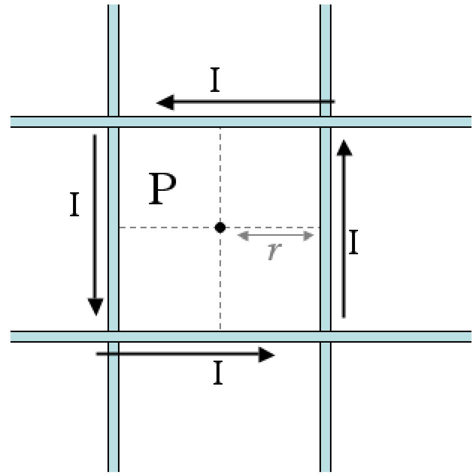
A17/B15/C16: Consider a circuit consisting of five identical resistors (each with the same R) connected in series with a 9-Volt battery. A current of 0.36 A flows through the circuit. What is the resistance of each resistor?
a. 125Ω
b. 25Ω
c. 3.2Ω
d. 100Ω
e. 5Ω

ANSWER: The current must be the same through each circuit element – this holds for the equivalent resistor as well.
$\epsilon = IR_{\text{eq}}$ can be rearranged:
$R_{\text{eq}} = \epsilon/I = 9V/0.36A = 25\Omega$.
Because all the resistors are in series, $R_{\text{eq}} = R_1 + R_2 + ... + R_5$. That is, the sum of the individual R values must be 25Ω. Because they're identical resistors, each individual resistor must have $R = 5\Omega$.

A18/B13/C14: When current is flowing in a superconductor, which statement is not true?
a. A battery is needed to keep the current going.
b. Electrical charges are moving.
c. The resistance is zero.
d. No power is given off in the form of heat.

Solution: **choice a is incorrect** (see section 21.3)

A19/B22/C21: Four wires in a plane carry equal currents I as shown. Point P is an equal distance r from all four wires. What is the strength of the magnetic field at point P?



a. $B = \frac{\mu_o I}{2\pi r}$

b. $B = \frac{\mu_o I}{4\pi r}$

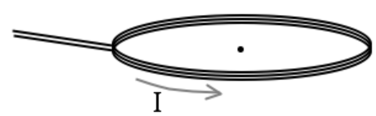
c. $B = \frac{2\mu_o I}{\pi r}$

d. $B = \frac{4\mu_o I}{\pi r}$

e. $B = \frac{\mu_o I}{8\pi r}$

ANSWER: We covered this in lecture on 11/23.
The direction of the magnetic field at point P due to each individual wire is out of the page (via the right hand rule). The four magnetic field vectors will add. The magnitude of the magnetic field due to each individual wire is determined via $B = \frac{\mu_o I}{2\pi r}$. The magnitude of the TOTAL magnetic field at point P is thus 4 times this: $B = \frac{4\mu_o I}{2\pi r} = \frac{2\mu_o I}{\pi r}$**.**

A20/B20/C25: A conducting wire carrying a current of 8.0 A is shaped into a tight stack of three circular loops as shown (i.e., it's not a solenoid). Each loop has a radius of 1.0 cm. The current travels in the same direction in each loop. What is the strength of the magnetic field at the point in the center of the loops?



NOTE: As discussed at the final exam, the value for choice "A" had a typo: The correct choice should read
15×10^{-4} **T or** 1.5×10^{-3} **T = 15 G,**
and that has been edited into the choices here. Good thing we caught that, as that turned out to be the correct answer, as discussed below!

a. 1.5×10^{-3} T = 15 G
b. 5.0×10^{-5} T = 0.5 G
c. 3.0×10^{-5} T = 0.3 G
d. 1.5×10^{-5} T = 0.15 G

ANSWER: For a single loop of wire carrying a current I, the current at the center of the loop is calculated via $B = \frac{\mu_o I}{2R}$, where R is the radius of the loop (equation 22.24).
For one loop carrying 8A, $B = \frac{(4\pi \times 10^{-7} TmA^{-1})(8A)}{(2)(0.01m)} = 5.0 \times 10^{-4}$ T (=5.0 Gauss).
For 3 loops, we add up the magnetic fields, the sum magnetic field is 1.5×10^{-3} **T (=15**

Gauss)
That is, the stack of 3 loops, each carrying 8 A, is effectively equivalent to a single loop carrying 24 Amps.

A21/B26/C27: Consider an air-core tokamak toroid consisting of a total of 5000 turns of conducting wire. Each turn carries 1000 A of current. Inside the toroid, a stream of electrons travels along a magnetic field line at a radius of 10 m from the center of the toroid. (Their path of motion is a tight helix which follows the magnetic field line.) What is the magnitude of the magnetic field line?
a. 10^{-4}T
b. 0.001 T
c. 0.01 T
d. 0.1 T
e. 1.0 T

ANSWER: For a toroid, B(r) for a toroid = $\frac{\mu_0 IN}{2\pi r} = \frac{(4\pi\times10^{-7}TmA^{-1})(1000A)(5000)}{2\pi 10m}$ = **0.1 T**

A22/B28/C23: A rectangular coil measuring 0.20 m × 0.50 m has 20 turns and is immersed in a uniform magnetic field of 0.030 T. If the orientation of the coil is varied through all possible positions, the maximum torque on the coil by magnetic forces is 0.080 N m. What is the current in (each loop of) the coil?
a. 3.0 mA
b. 1.33 A
c. 0.67 A
d. 0.27 A
e. 0.067 A

Solution: Because the torque τ = NBIAsin(θ), the maximum torque value will be $\tau_{\max}$ = NBIA.
We can solve for the current I = $\tau_{\max}$ / (NBA) =
(0.080 Nm)/(20 × 0.03T × 0.20 m × 0.50 m) = **1.33 A**

A23/B24/C19: An electromagnet consists of an air-core solenoid carrying a current I_1 in each loop; the strength of the magnetic field inside the solenoid is B_1. Then, the current is tripled (i.e., $I_2 = 3I_1$), while an iron core (assume $\mu/\mu_0 = 500$) is inserted into the solenoid. What is the final value of the magnetic field B_2 in terms of B_1?
a. $B_2 = 4500B_1$
b. $B_2 = 1500B_1$
c. $B_2 = 500B_1$

d. $B_2 = 167B_1$
e. $B_2 = 55.6B_1$

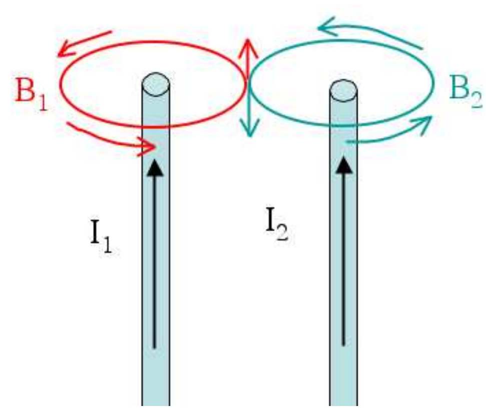
ANSWER: The strength of the B-field inside an air-core solenoid is $\mu_o I n$ (n = number of turns per unit length). So if I is tripled, B is also tripled. The introduction of the Fe core further increases the B-field by a factor of μ/μ_0. That is, for a solenoid with ferromagnetic material as its core, $B = \mu I n$.
The final answer is $B_2/B_1 =$ **1500 (b).**

A24/B23/C24: The magnetism of ferromagnetic materials such as iron has its origin in the intrinsic magnetic moment of electrons that is associated with their
a. orbital angular momentum
b. spin angular momentum
c. electric charge
d. being magnetically hard
e. being magnetically soft

ANSWER: **Spin angular momentum:** See section 22.11

A25/B27/C28: Two long parallel wires 40 cm apart are carrying currents of 10 A and 20 A in the same direction. What is the magnitude of the total magnetic field at a point halfway between the wires?
a. 1.0×10^{-5} T
b. 2.0×10^{-5} T
c. 3.0×10^{-5} T
d. 4.0×10^{-5} T
e. 0

Because the wires carry currents in the same direction, their respective B-field lines will circulate in the same direction. At the midway point, the B-field vectors will be pointing in opposite directions. The magnitude of the net magnetic field at that point will be the difference between the B-fields from each wire separately.
The drawing on the right indicates the directions (though not relative magnitudes) of each wire's B-field.



At a point 20cm = 0.2m from the wire carrying 10A, the B-field will be
B $\frac{\mu_0 I}{2\pi r} = \frac{4\pi \times 10^{-7} TmA^{-1} 10A}{2\pi 0.20m} = 1.0 \times 10^{-5}$ T

At a point 20 cm from the wire carrying 20 A,
the magnitude of the magnetic field will be exactly twice that from the 10-A wire (since B is linearly proportional to I). So B will be 2.0×10^{-5} T.
The net magnetic field strength will thus be 2.0×10^{-5} T – 1.0×10^{-5} T = 1.0×10^{-5} **T.**

A26/B25/C26: Two parallel wires are separated by 0.25 m. Wire A carries 5.0 A and Wire B carries 10.0 A, with both currents in the same direction. The total magnetic force acting on 0.80 m of Wire A is:
a. half that on 0.80 m of wire B.
b. one-fourth that on 0.80 m of wire B.
c. directed toward Wire B.
d. directed away from Wire B.

(see section 22.8) The force per length on either wire is given by $F_1/l = F_2/l = \mu_o I_1 I_2 \ / \ 2\pi a$, where a is the distance of separation between the wires. That is, the force on 0.8 m of wire A will be identical to that acting on 0.8m of wire B. So choices a and b must be eliminated. Two wires carrying parallel currents will attract each other, so the answer is **"c"**.

A27/B21/C20: If an electron moves from right to left across this page and suddenly is subjected to a magnetic field directed into the page, what is the direction of the magnetic force acting on the electron?
a. Into the page
b. Out of the page
c. From the bottom to the top of the page
d. From the top to the bottom of the page
e. From the left to the right of the page

ANSWER: C.
To find the direction of the force vector, use the Right hand rule for a positively-charged particle: Thumb = $\vec{v}$ = left. Fingers = $\vec{B}$ = into page. Out of palm = $\vec{F}$ = down. Reverse direction for an electron. Final answer = **from bottom to top of page**

A28/B19/C22: You are using a mass spectrometer to analyze a sample consisting of a mixture of two unknown compounds with differing molecular masses. The atoms in the mixture are ionized (assume each atom has a charge $+1e$). Then they are sent through a velocity selector so that those with a velocity of $1.0{\times}10^5$ m/s are selected. Then, they are subjected to a uniform, constant magnetic field. They move in circular paths onto a photographic plate. The inferred radii of curvature are 20cm and 16cm, respectively. What is the ratio of

the molecular masses?
a. 5:1
b. 16:9
c. 25:16
d. 4:3
e. 5:4

ANSWER: It is tempting to use the equation $r = mv/qB$ to solve for the masses of each type of molecule; rearrange to get $m = qrB/v$. Notice, however, that you were not given the magnitude of the magnetic field (for molecules with atomic masses of tens of atomic mass units, a B-field strength of roughy 0.1 T would yield r∼20 cm, just to do a crude ballpark estimate.) To do this problem, you do not need the B-field strength. The value of the velocity given is also not needed.
Consider the ratio of the radii. For all molecules, q is the same, B is the same, and v is the same. So r = mv/qB means that r is directly proprtional to m. That is, $\frac{r_2}{r_1} = \frac{m_2}{m_1}$; e.g., increasing the atomic mass by a factor of **5/4** means you increase the radius of curvature by 5/4.

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A29/B40/C32: A long, straight conducting rod 1.5 m in length is moved perpendicular to a uniform magnetic field of 0.1 T. What constant velocity is required to induce an EMF of half a volt between the ends of the rod?
a. 1.7 m/s
b. 0.1 m/s
c. 3.3 m/s
d. 0.2 m/s
e. 2.6 m/s

Solution: For motional EMF, ϵ_{ind} = B l v.
v = ϵ_{ind} /(Bl) = (0.5 V)/(0.1 T × 1.5m) = **3.3 m/s**

A30/B30/C30: Consider a patient inside an MRI machine, where the magnetic field strength is 3 T and uniform. Calculate the magnetic flux through the topmost cranial plate in the patient's skull; assume for simplicity a flat circular cross-section with radius 9 cm oriented perpendicular to the magnetic field.
a. 4.4 Wb
b. 0.076 Wb
c. 0.85 Wb
d. 763 Wb
e. 24.1 Wb

Solution: $\Phi_B = BA\cos(\theta)$ where θ is the angle between the normal vector and the magnetic

field lines. Here, θ is zero and so cos(θ)=1.
$\Phi_B = 3$ T (π (0.09m)^2) = **0.076 Wb**

A31/B34/C38: A bar magnet is falling through a loop of wire. The north pole enters first. As the south pole leaves the loop of wire, the induced current (as viewed from above) will be:
a. clockwise.
b. counterclockwise.
c. zero.
d. along the length of the magnet.

Solution via Lenz' Law: As the south pole leaves, the magnetic field lines from the magnet are pointing downwards, but the magnitude of the magnetic field is decreasing. The induced current in the loop acts to "shore up" the decreasing magnetic field. It will rotate **clockwise as seen from above** to generate an induced B-field which points downward (right-hand rule: as seen from above, when your thumbs points downward, your fingers curl clockwise).

A32/B39/C34: Electricity may be generated by rotating a loop of wire between the poles of a magnet. The instantaneous induced current is greatest when:
a. the plane of the loop is parallel to the magnetic field.
b. the plane of the loop is perpendicular to the magnetic field.
c. the magnetic flux through the loop is a maximum.
d. the plane of the loop makes an angle of 45° with the magnetic field.

Solution: The change in magnetic flux is greatest when the **plane of the loop is PARALLEL to the magnetic field**; this is when the component of velocity perpendicular to the B-field, $v_\perp$, is greatest.
To go into this in a little more detail: Consider the normal vector $\vec{A}$ for a loop; $\vec{A}$ is perpendicular to the plane of the loop. Define θ to be the angle between $\vec{A}$ and $\vec{B}$.
When the plane of the loop is perpendicular to the B-field lines, $\vec{A}$ and $\vec{B}$ are parallel, and so $\theta = 0°$ (or 180°). The magnetic flux through the loop, $\Phi_B = BAcos(\theta)$, is maximized when $\theta = 0°$. But the CHANGE in Φ_B is zero at this point in the loop's cycle. The induced

EMF will be $\epsilon_{ind} = -Nd\Phi_B/dt = NBAsin(\theta)$ which is zero when $\theta = 0°$.
When the plane of the loop is parallel to the B-field lines, $\vec{A} \perp \vec{B}$, so $\theta = 90°$ (or $270°$). The magnetic flux through the loop, $\Phi_B = BAcos(\theta)$, is zero (because cos(90°)=0.) The CHANGE in Φ_B is maximized at this point in the loop's cycle. $\epsilon_{ind} = -Nd\Phi_B/dt = NBAsin(\theta)$, the magnitude of which is maximized for $\theta = 90°$ or $270°$.

A33/B33/C33: A planar loop consists of 50 turns of wire, each enclosing an area of 0.05m^2. It is initially positioned perpendicular to a uniform magnetic field of 0.10 T. It is then rotated through 180° in a time of 0.5 seconds. Calculate the magnitude of the induced EMF.
a. 5.0 V
b. 0.1 V
c. 0.5 V
d. 1.0 V
e. 2.0 V

Solution: We use Faraday's Law: $\epsilon_{\text{ind}} = N\frac{\Delta\Phi_B}{\Delta t}$, where the minus sign has been dropped since we are only concerned with the magnitude of the induced emf.
$\Delta\Phi_B = \text{B} \times \Delta\text{A}$, where the change in area (as viewed along the B-field lines) = 2× the area given.
So $\epsilon_{\text{ind}} = (50)(0.10\text{T})(2 \times 0.05\text{m}^2)/(0.5\text{s}) = \mathbf{1.0\ V}$

A34/B31/C39: A planar loop consists of 4 turns of wire, each enclosing an area of 0.02 m^2. It is positioned perpendicular to a uniform magnetic field whose magnitude increases at a constant rate from 2.0 T to 12.0 T in 1.0 s. The coil's total resistance is 0.8Ω. What is the magnitude of the induced current?
a. 0.6 A
b. 1.0 A
c. 0.8 A
d. 1.2 A
e. 4.0 A

Solution: We can calculate the induced EMF via Faraday's Law: $\epsilon_{\text{ind}} = N\frac{\Delta\Phi_B}{\Delta t}$, where the minus sign has been dropped since we are only concerned with the magnitude of the induced emf.
The change in magnetic flux $\Delta\Phi_B$ is due to the change in B, i.e., $\Delta\Phi_B = \Delta B \times$ Area.

$\epsilon_{\text{ind}} = N\frac{\Delta\Phi_B}{\Delta t} = 4\frac{10.0T \times 0.02m^2}{1.0s} = 0.8V$
The induced current I = ϵ_{ind}/R = 0.8V / 0.8Ω = **1.0 A.**

A35/B29/C35: A magnet moving past an object will produce eddy currents in the object if the object:
a. is magnetic material only.

b. is an insulator.
c. is a liquid.
d. is a conductor.
e. is shaped like a hollow cylinder

Answer: **D: conductor**

36: An ideal transformer is one that:
a. works with direct current.
b. has a turn ratio, N_2/N_1, equal to 1.
c. experiences no power loss.
d. has an output frequency of 60 Hz.
e. makes use of permanent magnets.

ANSWER: **No power loss. (C)**

A37/B36/C29: An ideal transformer is used to increase the 25 kV (peak AC voltage) output of a power plant to the transmission line voltage of 300 kV (peak). If the primary winding has 60 turns, how many turns must the secondary have?
a. 12
b. 60
c. 144
d. 300
e. 720

Solution: For an ideal transformer, $\frac{\Delta V_2}{\Delta V_1} = \frac{N_2}{N_1}$. As this is a "step-up" transformer, we need N_2 to be greater than N_1
$N_2 = N_1 \frac{\Delta V_2}{\Delta V_1} = (60)(300000/25000) = (60)(12) = \mathbf{720}$

A38/B37/C40: You have an AC generator consisting of a 50-turn coil, with each coil having an area of 0.1m^2, rotating inside a uniform magnetic field of 0.1 T. How quickly do you need to rotate the loop in order to achieve a maximum instantaneous EMF of 10 V? Note that the responses below are in units of Hz (revolutions per second, or cycles per second), not radians/sec!
a. $10/\pi$ Hz = 3.18 Hz
b. $50/\pi$ Hz = 15.91 Hz
c. 200 Hz

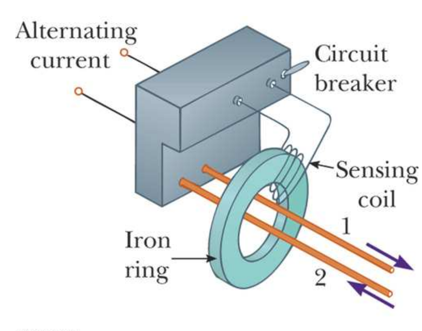
d. $20/\pi$ Hz = 6.37 Hz
e. 20 Hz

Solution: In an AC generator, the EMF as a function of time will follow $\epsilon(t) = \mathrm{NBA}\omega\sin(\omega t)$. Here, ω is the angular speed, measured in radians/sec. The maximum instantaneous EMF you can get is will be $\epsilon_{\max} = \mathrm{NBA}\omega$.
Solve for ω:
$\omega = \epsilon_{\max}/(\mathrm{NBA}) = (10\mathrm{V})/(50 \times 0.1T \times 0.1m^2) = 20$ rad/sec.
The frequency $f = \frac{\omega}{2\pi} = \frac{20rad/sec}{2\pi} = \mathbf{10/\pi}$ **cycles per second.**

A39/B32/C37: Electrostatic fields can be generated by point charges, but electric fields can also be generated by a magnetic flux which changes in time. What do both types of electric fields have in common?
a. Both are conservative fields.
b. Both are non-conservative fields.
c. Both types of electric fields start on positive charges and end on negative charges.
d. None of the above.

As discussed in section 23.4, the electric field generated by $d\Phi_B/dt$ is a non-conservative field. If a conducting loop is present and the electric field can drive charge all the way around the loop, then a non-zero amount of work was done to get the charge to move back to its original position. These electric fields are non-conservative, while the electrostatic fields introduced back in chapter 19/20 are conservative. Choices A and B are rejected.
As discussed in section 23.4, the electric field generated by a change in magnetic flux over time can occur in a region where there are no point charges present. That is, such an electric field can exist in free space. The field lines form closed loops, with no beginning/end. This contrasts with electrostatic field lines which start/end on point charges. Choice C is rejected.
Final answer is **D, none of the above.**

A40/B35/C36: Suppose you work for a company which manufactures ground-fault interrupters (GFI; schematic shown at right). You are charged with re-designing the product such that the GFIs become relatively more sensitive to the rapid changes in current associated with (accidental) connections to ground. Which of the following re-design actions will NOT increase the GFI's sensitivity? (assume that the distance between wires 1 and 2 is negligible compared to the radius of the iron ring.)
a. Decrease the radius of the iron ring



b. Replace the iron ring with a ring composed of a hard
magnetic material; the permanent magnetic field means there is always a non-zero magnetic flux through the sensing coil.
c. Increase the number of turns in the sensing coil.
d. Change the composition of the iron ring to a soft magnetic iron alloy material that has an increased permittivity.
e. Use a thicker iron ring, thereby increasing both the region where strong magnetic fields occur and the area of each coil in the sensing coil.

Choice A is okay: when current in wire 2 drops to zero and there is a net non-zero magnetic field due to the current in wire 1, that magnetic field strength will be quantified as $B(r) = \frac{\mu_o I}{2\pi r}$. Decreasing the radius of the iron ring thus brings the sensing coil towards regions of higher magnetic field strength, thereby increasing the magnetic flux through the sensing coil.
Choice D will increase the net B-field and thus Φ_B through the sensing coil.

Choice E directly leads to an increase in Φ_B through the sensing coil.

Choice C will increase the induced EMF in the sensing coil, in accordance with Faraday's Law, $\epsilon_{\text{ind}} = -N\frac{\Delta\Phi_B}{\Delta t}$: increasing N will directly increase ϵ_{ind}.
Choice B will decrease sensitivity to changes in Φ_B through the sensing coil – if there is already a non-zero flux magnetic flux present, additional rapid changes will be more difficult to detect. Moreover, if a short occurs, and a net B-field around the ring is produced by wire 1, the hard magnetic material is more difficult to magnetize (it won't quickly respond and produce its own strong B-field inside the iron ring), and thus changes in Φ_B through the sensing coil may not be very strong or very rapid.