1. A metal bar of length 0.3 m is moved to the right with a speed of 0.1 m/s. The bar is oriented perpendicular to its direction of motion. It is passing through a region of uniform magnetic field of magnitude 10^{-2} T oriented perpendicular to the plane swept out by the bar, as in the figure. What is the potential difference between the two ends of the bar as it moves through the magnetic field?

(a) 3 mV
(b) 1 mV
(c) 3 V
(d) 0.3 mV
(e) 3×10^{-4} V/m

answer (d). Think of the bar as part of a square loop three sides of which are imaginary, calculate the changing flux through the loop, and an emf is set up in the bar that cancels the induced emf when charges move to the bar's ends. The field is constant, so the mag flux through the loop changes because the area does: A = Lvt, where L is the bar's length and we start the clock when the loop has no area. Thus $\Phi_B = B \times$ Lvt) [there are no cosine factors with the orientation described] and $d\Phi_B/dt$ = BLv. By Faraday, this is the emf, given by $BLv = (10^{-2}\ \text{T})(0.3\ \text{m})(0.1\ \text{m/s}) = 0.3$ mV

2. A coil with an inductance of 0.4 H and a resistance of 10 Ω is connected to a 100 V battery. The maximum energy stored in the magnetic field of the coil is

(a) 2 J
(b) 20 J
(c) 10 J
(d) 40 J
(e) cannot be determined from the information given

answer (b) Max energy in the coil when the current has built up to its max value, given by I = V/R = (100 V)/(10 Ω) = 10 A. The energy in the field is at that point the energy in the inductor,
$U = \frac{1}{2} LI^2 = \frac{1}{2} (0.4\ \text{H})(10\ \text{A})^2 = 20$ J.

3. Suppose a small cylinder of a paramagnetic substance and a small cylinder of a diamagnetic substance are placed between the (parallel) horizontal pole pieces of a strong magnet, so that they are aligned with their axes along the direction of the field lines. Consider two cases: the cylinders one atop the other, and the cylinders side by side—see the figure. Will they attract or repel each other?

(a) attract if one atop the other; attract if side by side
(b) attract if one atop the other; repel if side by side
(c) repel if one atop the other; attract if side by side
(d) repel if one atop the other; repel if side by side
(e) none of the above

Answer. (c) In the picture (refer to your exam), the paramagnet behaves as if it has a N pole at the top and the diamagnet behaves as if it has a S pole at the top – in that way the field is bigger inside the paramagnet and smaller inside the diamagnet. Then with one on top of the other there is the repulsion of two like poles and with one aside the othr there is the attraction of unlike poles.

4. True or false: The magnetic field lines go out in radial fashion all the way around the N-pole of a magnet.

(a) True
(b) False

answer (b). They could only do so if there were a magnetic monopole at the north pole, and there is no such thing. Some lines must be going into the N pole, in contrast to an electric dipole, as we have repeatedly emphasized in class.

5. An AC circuit contains a parallel-plate capacitor and a long, cylindrical solenoid. Suppose that all the linear dimensions of the apparatus, including the wire radii, are scaled down by a factor of 2. (Note that the turn density doubles.) How would the resonant frequency of the circuit change?
(a) It doubles.
(b) It increases by a factor of 4.
(c) It decreases by a factor of 4.
(d) It decreases by a factor of 2.
(e) none of the above

answer (a). The resonant frequency is $(LC)^{-1/2}$. With $C = \varepsilon_0 A/d$, we have $A \to A/4$, $d \to d/2$, so that $C \to C/2$, while for the inductor use $A \to A/4$, length $\to$ length/2, $n \to 2n$ so that $L = \mu 0\, A \times \text{length} \times n^2 \to L/2$. Thus the frequency $\to$ frequency $\times (2 \times 2)^{+1/2}$ = frequency $\times$ 2.

6. We used a step-down transformer in a class demonstration to weld together two nails that were in series with the secondary coil of the transformer. One of the following statements is true—which one?
(a) The nails welded because of the increased voltage across the secondary coil.
(b) A step-up transformer would have done the job just as well.
(c) The fact that the emf in the secondary coil is induced and therefore has a nonconservative electric field associated with it is crucial to the welding operation.
(d) None of the other statements is true.
(e) The welding worked because the current was AC.

answer (d). The nails weld because of the large current in the secondary coil

7. An electron (mass *m*) with nonrelativistic kinetic energy *K* enters a region of crossed electric and magnetic fields (the fields are perpendicular to each other), with the electron moving perpendicular to both fields. The magnitude *E* of the electric field is adjustable. What should you choose for *E* so that the electron moves through the field region undeflected?

(a) $\dfrac{B}{\sqrt{2K}}$

(b) $B\sqrt{\dfrac{2K}{m}}$

(c) $\sqrt{2mK}\,B$

(d) $\sqrt{\dfrac{2K}{mB^2}}$

(e) $B\sqrt{\dfrac{m}{2K}}$

answer (b). The undeflected speed is $v = E/B$, so that $E = vB$. But the kinetic energy $K = \frac{1}{2} mv^2$, or $v = (2K/m)^{1/2}$. Dimensional analysis would also be helpful here.

8. The planar circular plates of a capacitor are being charged. At a given moment, the charge is being built up at the rate of 1 C/s. The plates have a radius $R = 0.1$ m and a separation $d = 1$ cm. Consider the magnetic field due to the displacement current midway between the plates at a radius equal to half the plate radius. What happens to this field if the distance *d* between the plates is halved?
(a) It will be nearly unchanged.
(b) It will increase by a factor that cannot be calculated because of lack of symmetry.

(c) It will halve.
(d) It will double.
(e) It will increase by a factor of four.

answer (a). The electric field whose changing flux induces the mag field is independent of the plate separation for large plates and/or small separation. that is a good approx here.

9. You can use Ampere's law to find the magnetic field of a toroidal solenoid. Consider one that is formed from a tube of circular cross section of radius 1 cm that is bent into a circle—the center line of the tube forms a circle of radius 50 cm. The solenoid is wound with n turns per unit length. What approximate turn density is needed to give a field of strength 3×10^{-4} T down the center line of the tube when the wires carry 0.25 A?
(a) 10 turns per m
(b) 100 turns per m
(c) 10 turns per cm
(d) 50 turns per cm
(e) 0.5 turns per cm

answer. (c) Let R be the radius of the large circle made by the torus. Make an Ampere's law circle down the center of this circle. The current enclosed is $I \times N = I \times 2\pi R\, n$, where N is the total number of turns and n is the turn density. μ_0 times this current equals $B \times$ path length $= B \times 2\pi R$, because B is parallel to the path and is constant in value over the path, so that it comes out of the integral. Thus the $2\pi R$ cancels and $B = \mu_0 I n$, or $n = B/\mu_0 I = (3 \times 10^{-4}\ \text{T})/[(4\pi \times 10^{-7}\ \text{SI units}) \times (0.25\ \text{A})] = 10^3$ turns per meter = 10 turns per cm.

10. The term "impedance matching" refers to
(a) how filters take out unwanted frequencies.
(b) electronic devices to allow current to flow in one direction only.
(c) the transformation of DC to AC.
(d) the way power is delivered from one part of an AC circuit to another.
(e) making the capacitive and inductive reactances equal.

answer (d).