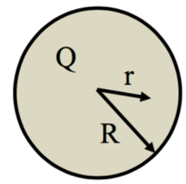
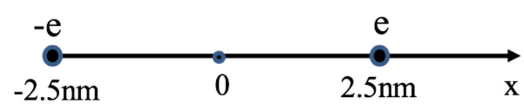
1) [*8 pts*] **Gauss' Law**. A solid insulating sphere of radius R is uniformly charged with total charge Q and placed at the origin. Use Gauss' law to determine the electric field for a radius r < R (i.e. inside the sphere) :

solid insulating sphere



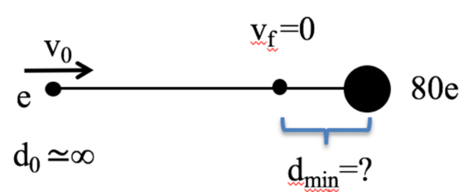
(A) E(r) = kQ/r^2
(B) E(r) = kQr/R^3 correct
(C) E(r) = kQr/2R^3
(D) E(r) = kQ/rR
(E) E(r) = kQ/2r^2
(F) E(r) = kQr^2/R^4

2) [*8 pts*] **Electric Field**. An electron and a proton are separated by a distance of 5nm (see figure). The electric field at their midpoint is :



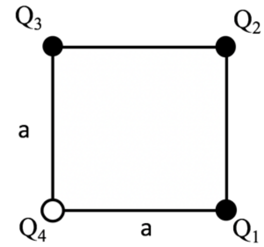
(A) 0
(B) 2.3×10^6 N/C in the direction of the electron
(C) 2.3×10^6 N/C in the direction of the proton
(D) 1.15×10^8 N/C in the direction of the electron
(E) 1.15×10^8 N/C in the direction of the proton
(F) 4.6×10^8 N/C in the direction of the electron correct
(G) 4.6×10^8 N/C in the direction of the proton

3) [*6 pts*] **Electric Potential Energy**. A proton (charge e and mass m) is approaching a stationary mercury nucleus (charge 80e) head on. When it is far away, the proton's speed is v_0. What is the distance of closest approach d_{min} of the proton to the nucleus ?



(A) 0
(B) $[k\, e / (mv_0)]^{1/2}$
(C) $80\, k\, e / (mv_0)$
(D) $2\, k\, e^2 / (mv_0^2)$
(E) $[\, 80\, k\, e^2 / (mv_0^2)\,]^{1/2}$
(F) $160\, k\, e^2/(mv_0^2)$ correct

4) [*8 pts*] **Electric Potential**. Four charges of equal magnitude are placed on the corners of a square of sidelength a. Three of the charges are positive ($Q_{1,2,3} = Q > 0$) and 1 is negative ($Q_4 = -Q$). The total potential energy of this configuration (with the convention $U(r\to\infty) = 0$) is :



(A) $4\ kQ^2/a$
(B) $2\ kQ^2/a$
(C) kQ^2/a
(D) 0 correct
(E) $-2\ kQ^2/a$
(F) $-4\ kQ^2/a^2$

5) [*6 pts*] **Energy in Capacitor**. An air-filled insulated parallel-plate capacitor is held at a fixed charge. If the separation of its plates is doubled, the electric energy stored in the capacitor is :

(A) ¼ of the original
(B) ½ of the original
(C) unchanged
(D) doubled correct
(E) quadrupled

6) [*8 pts*] **Electric Power**. A light bulb has a power output of 60W. The bulb is connected to a 24 V battery. The current drawn from the battery and the resistance of the light bulb are :

(A) 0.2 A and 0.104 Ω
(B) 0.2 A and 1.4 Ω
(C) 0.4 A and 0.104 Ω
(D) 0.4 A and 240 Ω
(E) 2.5 A and 0.104 Ω
(F) 2.5 A and 9.6 Ω correct

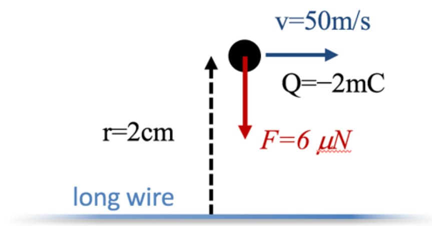
7) [*6 pts*] **Discharging RC Unit**. Consider a simple RC circuit with an initially charged capacitor of capacitance C = 1mF and unknown resistance R. When closing the switch, the current drops to 10% of its initial value within a time of 1.8s. The resistance in this circuit is :

(A) 53 Ω
(B) 140 Ω
(C) 482 Ω
(D) 783 Ω correct
(E) 1280 Ω
(F) 4145 Ω

8) [*6 pts*] **Lorentz Force**. A laboratory has its four corridors marked with the north, south, east and west directions. It is in a uniform magnetic field that points downward (into the ground); there is no electric field. A negatively charged particle moves north. The Lorentz force on the particle points to :

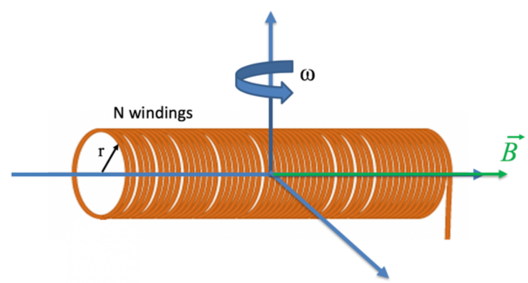
(A) North
(B) South
(C) East (correct)
(D) West
(E) Up
(F) Down

9) [8 *pts*] **Magnetic Force from Current**. A long straight wire carries an unknown current I. A negatively charged particle (Q =-2mC) at 2 cm from the wire has a velocity of 50m/s along the direction of the wire (see figure). The particle experiences a force of 6 μN towards the wire. Determine the magnitude and direction of the current.



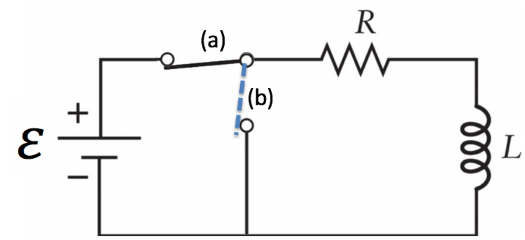
(A 1.91 A along the electron's velocity
(B) 1.91 A opposite the electron's velocity
(C) 6 A along the electron's velocity
(D) 6 A opposite the electron's velocity correct
(E) 18.8 A along the electron's velocity
(F) 18.8 A opposite the electron's velocity

10) [*6 pts*] **Magnetic Induction**. To determine the strength B of a uniform magnetic field in his laboratory, an engineer uses a solenoid (a long magnetic coil of radius **r** with **N** windings), rotating it at an angular frequency $\omega = 2\pi f$ about an axis perpendicular to the magnetic field and to the symmetry axis along the solenoid. He detects an induced EMF with a maximal value of ε. The magnetic field strength is :



(A) $B = \varepsilon / N\pi r^2\omega$ correct
(B) $B = \varepsilon\omega / N\pi r^2$
(C) $B = \varepsilon\pi r^2 / N\omega$
(D) $B = 2\pi r / N\omega\varepsilon$
(E) $B = N\varepsilon / 2\pi r\omega$
(F) $B = \varepsilon / N2\pi r\omega$

11) [*8 pts*] **RL Unit**. A resistor (resistance R) and an inductor (inductance L) are connected in series to a battery with EMF ε, with switch initially at position (a) (see figure). At t=0, the switch is flipped to position (b) to remove the battery from the circuit (see figure), and the current starts to drop off as $I(t) = I_0 \exp(-t/\tau)$. The magnitude of the voltage across the inductor at t=0 and after a long time are :



(A) 0 and 0
(B) 0 and ε
(C) 0 and RI_0
(D) RI_0 and 0 correct
(E) RI_0 and RI_0
(F) ε and RI_0

12) [*6 pts*] **Displacement Current**. An air-filled parallel-plate capacitor is being charged leading to an increase of its electric field from 0 to 12000 V/m over a time interval of 1.5 s. Compute the displacement current through a $(25\ \text{cm})^2$ area parallel to the plates inside the capacitor.

(A) 1.8×10^{-10} A
(B) 4.4×10^{-9} A correct
(C) 1.7×10^{-9} A
(D) 1.0×10^{-8} A
(E) 0.33×10^{-7} A
(F) 0.33×10^{-5} A

13) [*8 pts*] **EM Plane Wave**. The electric field of a plane wave is described by $\vec{E} = E_0 \sin(ky-\omega t)\,\hat{k}$. The velocity and the magnetic field of this wave are oriented in :

(A) x- and y-direction
(B) x- and z-direction
(C) y- and x-direction correct
(D) y- and z-direction
(E) z- and x-direction
(F) z- and y-direction

14) [*8 pts*] **Energy in EM wave**. An electromagnetic wave has a B-field of amplitude $2*10^{-6}$ T. The wave irradiates an area of 0.5 m^2. Calculate the intensity of the wave and the time it takes to deposit 1 kJ onto the irradiated area.

(A) 1.59×10^{-6} W/m^2 and 1.3×10^8 s
(B) 1.59×10^{-6} W/m^2 and 25 s
(C) 477 W/m^2 and 4.2 s correct
(D) 477 W/m^2 and 1.1 s
(E) 1.3×10^5 W/m^2 and 0.015 s
(F) 1.3×10^5 W/m^2 and 0.12 s