1. Four charges are arranged on the four corners of a square as shown in the diagram. If the electric potential is defined to be zero at infinity then it is also zero at

(a) point V only.
(b) points II and IV and V.
(c) points I and III.
(d) none of the labeled points.

Answer (b) These points lie halfway between the positive and negative charges.

2. A small positive charge \( q \) is brought from far away to a distance \( r \) from a positive charge \( Q \). In order to pass through the same potential difference a charge \( 2q \) should be brought how close to the charge \( Q \). (Assume the initial charge \( q \) has been removed.)

(a) a distance \( r/2 \).
(b) a distance \( r \).
(c) a distance \( 2r \).
(d) a distance \( 4r \).

Answer (b): Electric potential difference depends only on the charge \( Q \), not on the charge moving through it.

3. Consider two different charged spherical conductors, Sphere A with radius \( r = a \) and Sphere B radius \( r = b \) with \( b > a \). If the conductors are brought into contact then which of the following statements are true:

(a) Sphere A has more charge and higher charge density.
(b) Sphere A has more charge but lower charge density.
(c) Sphere A has less charge but higher charge density.
(d) Sphere A has less charge and lower charge density.

Answer (b): In contact the two spheres will have the same potential, and thus the sphere with the larger radius must have the larger charge. \((V = kQ/R \Rightarrow Q \propto R)\). However charge density is lower for objects with larger radius of curvature.
4. A negative charge, if free, tries to move
   (a) from low potential to high potential.
   (b) toward infinity.
   (c) away from infinity.
   (d) from high potential to low potential.

   Answer (a): Positive charges go from high to low, and negative charges move the opposite way.

5. Two resistors are connected in series. The first has twice the resistance of the second. The current in the first resistor is:
   (a) twice the current in the second resistor.
   (b) the same as the current in the second resistor.
   (c) half the current in the second resistor.
   (d) one quarter the current in the second resistor.

   Answer (b): Charge is conserved. What flows in must flow out. Potential drops across a resistor, but current does not.

6. A capacitor is connected to the terminals of a 3 Volt battery. A second identical capacitor is connected to the terminals of a 9 Volt battery.
   (a) The first capacitor has 3 times the charge of the second.
   (b) The first capacitor has nine times the charge of the second.
   (c) The first capacitor has one third the charge of the second.
   (d) The two capacitors have equal charge because they are identical.

   Answer (c): For fixed capacitance charge is proportional to voltage difference.

7. The plates of a parallel plate capacitor are attached to the terminals of a battery. The plates are then moved further apart. Which of the following statements are true.
   (a) The electric field decreases and the electric potential stays the same.
   (b) The electric field stays the same and the electric potential increases.
   (c) The electric field decreases and the electric potential decreases.
   (d) Both the electric field and the electric potential stay the same.

   Answer (a): The battery fixes the potential drop, but since the plates are further apart the electric field $E = -\frac{dV}{dx}$ must be less.
8. The half-life of cobalt-60 is 5.3 years, while that of strontium-90 is 28 years. Suppose you have a sample of each, such that they initially contain equal numbers of atoms of these nuclides. How will the activities (number of decays per unit time) of the samples compare?

(a) The activities cannot be compared without more information.
(b) The activity of the strontium-90 sample will be greater.
(c) The activity of the cobalt-60 sample will be greater.
(d) The activities will be equal.

Answer (c): A shorter half-life means more decays per unit time, which means a higher activity if the number of nuclei are the same.

9. Modern nuclear bomb tests have created an extra high level of $^{14}\text{C}$ in our atmosphere. When future archaeologists date samples from this era, without knowing of this testing, their dates will be

(a) too young.
(b) too old.
(c) correct, since $^{14}\text{C}$ from bomb tests is different from that produced naturally.
(d) correct, because modern biological materials do not gather $^{14}\text{C}$ from bomb tests.

Answer (a): They will levels of $^{14}\text{C}$ higher than usual for something of that age, and will assume this is because the sample has not been dead for as long as it has, rather than because it absorbed more $^{14}\text{C}$ than when it was alive.

Part II

1. The following circuit has three identical light bulbs $A$, $B$ and $C$ connected with a non zero resistor $R$ to an ideal battery with $\mathcal{E}$.

![Circuit Diagram]

(a) Rank the bulbs in order of their brightness explaining your reasoning clearly.
   $A$ is brightest since all the current flows through $A$. $C$ is least bright since the current divides between $B$ and $C$, but the path with $C$ has the extra resistor.

(b) If bulb $A$ is unscrewed (hence breaking the circuit at that point) what happens to the brightness of the other two bulbs. Which bulb, if any, is brighter?
   All lights go out, since there is no return connection to the battery.
(c) If bulb $B$ is unscrewed instead (hence breaking the circuit at that point) what happens to the brightness of the other two bulbs. Which bulb, if any, is brighter? The effective resistance has now increased because we have reduced the paths for it to take. Thus bulb $A$ will dim. As a consequence there is now a bigger potential drop across $C$, so it will brighten. $A$ and $C$ will be equally bright since they are in series.

(d) If each element in the circuit, including the resistor, has a resistance of 12 $\Omega$, what is the equivalent resistance of the circuit? The resistor and bulb $C$ are in series and have effective resistance 24 $\Omega$. These are in parallel with $B$, so the effective resistance of this combination is $1/((1/12) + (1/24)) = 1/(3/24) = 8$ $\Omega$. This is in series with bulb $A$, so the effective resistance is 20 $\Omega$.

2. The circuit below has had the switch in position $a$ for a long time. At time $t = 0$ the switch is thrown to position $b$. Suppose $E = 12.0$ V, $C = 10.0$ $\mu$F, $R = 20.0$ $\Omega$

![Circuit Diagram]

(a) What is the current through the resistor just before the switch is thrown to position $b$? $I = 0$

(b) What is the current through the resistor just after the switch is thrown? $I = V/R \Rightarrow I = 0.6$ A

(c) What is the charge across the capacitor just before the switch is thrown? $Q = CV \Rightarrow Q = 120mC$

(d) What is the charge on the capacitor just after the switch is thrown? Charge does not change instantaneously so $Q = 120$ mC

(e) What is the charge on the capacitor at time $t = 0.3$ msec after the switch is thrown? $q = q_0e^{-t/RC}$, where $RC = 0.2msec$. So $Q = 26.8mC$
3. Polonium-218 can decay by alpha decay or by beta decay.

(a) Write down the complete nuclear equations for both modes of decay.

\[ ^{218}_{84}\text{Po} \rightarrow ^{214}_{82}\text{Pb} + \alpha \]

\[ ^{218}_{84}\text{Po} \rightarrow ^{218}_{85}\text{At} + \beta \]

(b) Calculate the energy released per gram of Polonium-218 for each mode of decay.

We first find the mass deficit, which is the mass of the reactants - mass products. Next find what energy is released when this mass is lost. For \(\alpha\) decay \(\Delta m = 218.008965 - 213.999798 - 4.002602 = 0.00656\) u. So \(\Delta E = (0.00656\text{u})(931.5 \text{ Mev/u}) = 6.1\) Mev. For \(\beta\) decay \(\Delta m = 218.008965 - 218.008685 = 0.00028\) u. Note: We do not include the \(\beta\) because the product includes one extra atomic electron, so the mass of the beta electron is included already. So \(\Delta E = (0.00028\text{u})(931.5 \text{ Mev/u}) = 0.26\) Mev.

4. A potential difference of 10,000 V exists between two parallel plates which are separated by 10 cm. An electron is released from the negative plate at the same instant a proton is released from the positive plate.

(a) What is the kinetic energy of each particle as they reach the opposite sides? State your answer in units of Joules and electron volts.

\[ \Delta KE = -\Delta u = -q\Delta V = -(-1.6 \times 10^{-19})(10,000) = 1.6 \times 10^{-15} \text{ J} \]

(b) With what velocity does each of the particles hit the opposite plates?

By conservation of energy we set \(\Delta KE = \frac{1}{2}mv^2 = qV \Rightarrow v = \sqrt{2qV/m}\). For an electron this gives \(v = \sqrt{2(1.6 \times 10^{-15})/(9.11 \times 10^{-31})} = 5.93 \times 10^7\) m/s and for the proton this is \(v = \sqrt{2(1.6 \times 10^{-15})/(1.67 \times 10^{-27})} = 1.38 \times 10^6\) m/s.

(c) What is the acceleration of each particle?

\[ a = F/m = qE/m \]

assuming gravity is negligible compared with the electric force (it is!). \(E = V/d = 10,000/0.1 = 100,000\) V/m (or Joules/Coulomb). so for the electron \(a_e = (-1.6 \times 10^{-19})(100,000)/(9.11 \times 10^{-31}) = -1.75 \times 10^{16}\) m/s\(^2\) and for the proton \(a_p = (1.6 \times 10^{-19})(100,000)/(1.67 \times 10^{-27}) = 9.58 \times 10^{12}\) m/s\(^2\).