Study Guide for Part Two
ELECTRIC POTENTIAL

Electric Potential

A. Review: potential energy — S-9
1. work and energy
2. conservation of energy law: $KE_i + PE_i + W_{added} = KE_f + PE_f + E_{lost}$
3. gravitational potential energy
4. electric potential energy

B. Electric Potential — S-10,11,12
1. definition: $V = PE_{el} / q_{test}$
2. CAUTION: ELECTRIC POTENTIAL & ELECTRIC POTENTIAL ENERGY ARE NOT THE SAME!: $\Delta PE = q\,\Delta V$
3. units: 1 Volt = 1 Joule / 1 Coulomb
4. for a point charge: $V = k\,q\,/r$ (V can be + or -)
5. for several point charges: $V = \Sigma\, k\, q_i\, /r_i$ add as scalars!
6. for an extended charged object: add or integrate
   a) line
   b) on axis of a ring

C. Relation between Electric Field and Potential — S-13
1. V from E (integration): $\Delta V = -\int \mathbf{E} \bullet d\mathbf{s}$
   a) parallel plates
   b) coaxial cylinders
   c) spheres
2. E from change in V: $E_x = -dV/dx$; $E_y = -dV/dy$
   a) parallel plates
   b) coaxial cylinders
   c) spheres
3. equivalent units for electric field: 1 Nt/C = 1 V/m

D. The Cathode Ray Tube (CRT) — S-14

Supplementary Problems (S-):

9) How much energy (neglect energy lost due to air resistance) is necessary to lift a mass of 20 kilograms from the earth's surface up to the point where it will balance between falling back to earth and falling forward to the moon? (Use your results from problem S-1 of the previous part and initially neglect the effects of the moon on the energy.) How much less energy is necessary because the moon helps pull the mass up?

10) Consider two charges (same as for problem S-3): q_A has a charge of 5 nCoul and is located at (5 m, 3 m); q_B has a charge of -4 nCoul and is located at (7 m, -2 m).
a) What is the electric potential at the origin due to q_A alone?
b) What is the electric potential at the origin due to BOTH charges?

11) What change in potential energy does a +6 μCoul charge experience in moving from a position where the potential is 60 volts to one where it is 35 volts? Express your answer in Joules and in eV. If the charge has a mass of 2 mg, and the charge was initially at rest, and if all the potential energy change went into changing the particles kinetic energy, how fast would the particle be going when it reached the 35 volt position?

12) a) Through what potential difference must an electron be accelerated to reach 1 million mph if it starts from rest? Should the final position have a voltage lower or higher than the starting position?
b) Will a proton require more, the same, or less voltage difference to go from rest to 1 million mph than the electron (be sure to explain your answer)?

13) Consider the situation of problem S-10 above (and problem S-3 from the previous section). Recall from problem S-3 that the electric field at the origin points down and to the left (at an angle of 241°.
a) At a position slightly displaced from the origin in a direction 241°, would the electric potential at this new point be higher, the same, or lower than at the origin?
b) At a position slightly displaced from the origin in a direction 151° (perpendicular to 241°), would the electric potential at this new point be higher, the same, or lower than at the origin?

14) A certain CRT works by heating a wire to boil electrons off it. These electrons are then accelerated by an accelerating voltage applied across parallel plates with a hole in the middle of each. The electrons are then deflected by passing the beam between another pair of plates with a deflection voltage across the plates. If the accelerating plates have a distance of 5 mm between them and are 2 cm long, and the deflection plates have a distance of 1 cm between them and are 3 cm long, and if the distance between the middle of the accelerating plates and the deflection plates is 7 cm, and if the distance from the middle of the deflection plates to the screen is 8 cm, how far will the electron beam be deflected from straight through if an accelerating voltage of 50 volts and a deflection voltage of 5 volts is used?

Answers to Supplementary Problems:

9) 1.23×10^{9} Joules; 2.3×10^{6} Joules or about 0.2% easier.

10) a) +7.72 volts; b) +2.77 volts.

11) decrease of 1.5×10^{-4} Joules = 9.37×10^{14} eV; 12.25 m/sec = 27.4 mph.

12) a) 0.57 volts; ending position should be higher in voltage;

b) you're on your own on this one.

13) a) lower; b) the same.

14) 1.2 cm.

Capacitance and Dielectrics

A. Definition of capacitance S-15
1. definition: $C = Q/V$
2. units: Farad = Coul/Volt

B. Calculation of capacitance S-16
1. parallel plate
from Gauss' law: $E = 4\pi k\sigma = \sigma/\varepsilon_o$ where $\sigma = Q/A$
from $\Delta V = \int \mathbf{E} \bullet d\mathbf{s}$: $V = E\,d$
thus $V = (Q/\varepsilon_o A)\,d$ and so $C = Q/V = \varepsilon_o A/d$
2. coaxial cylinders

C. Combinations (effective capacitance)
1. series: $Q_1 = Q_2$; $V_1 + V_2 = V_{total}$
2. parallel: $V_1 = V_2$; $Q_1 + Q_2 = Q_{total}$
3. series and parallel

D. Energy stored in a capacitor S-17
$$PE = q_i V = \int V\,dq = \int (q/C)\,dq = Q^2/2C = \tfrac{1}{2}CV^2 = \tfrac{1}{2}QV$$

E. Dielectrics
1. with capacitors: $C_{with} = K\,C_{without}$
2. atomic description: dipoles

Supplementary Problems (S-):

15) Consider a 2 μFarad Capacitor with a voltage of 60 volts applied across it.
a) How much charge is stored on the capacitor?
b) If the voltage is doubled, will the capacitance double, stay the same, or decrease by half?

16) a) Design a parallel plate capacitor with a capacitance of 5 pF with vacuum between the plates.
b) Discuss what will change if a dielectric is placed between the plates with dielectric constant of 2.

17) Consider a voltage source of 120 volts and eight 5 μF capacitors.
a) If the capacitors are connected in parallel across the voltage supply and then the voltage source is removed (without discharging the capacitors):
(a1) what is the effective capacitance?
(a2) how much charge is stored? and
(a3) how much energy is stored in the system?
b) If the eight capacitors are now disconnected from their parallel arrangements (but not discharged) and reconnected in series (without the battery):
(b1) what is the total voltage across the system?
(b2) what is the effective capacitance?
(b3) how much charge is stored?
(b4) how much energy is stored in the system?

Answer to Supplementary problems:

15) a) 120 μCoul; b) stay the same (charge on capacitor would double).

16) your on your own - lots of correct answers (more incorrect ones!)

17) a1) 40 μF, a2) 4.8 mC, a3) 0.288 J;
b1) 960 V, b2) 0.625 μF, b3) 0.6 mC, b4) 0.288 J.

Current and Resistance

A. Current: $I = dQ/dt$; Amp = Coul/sec
inversely, $Q = \int I\, dt$

B. Ohm's law: $V = I R$
1. resistance: $R = \rho L / A$; R in Ω (ohm = volt/amp)
2. resistivity: ρ (depends on material); ρ in Ω*m

C. Electrical energy and power S-18,19
1. energy: $V = PE/q_{test}$, so energy = Q V
2. power: Power = Work/time, so $P = I V$ (Watt = amp volt)

D. Semiconductors

Supplementary Problems (S-):

18) Consider a 1.2 Watt light bulb that is designed to work with a 6 volt combination of batteries (four 1.5 volts in series).
a) What should the resistance of the bulb be?
b) If a higher power light bulb were desired, would a lower or higher resistance be necessary?

19) From the Capacitance and Dielectrics part, energy stored in a capacitor is PE = ½QV. From the Current & Resistance part, PE = QV. Explain why there is a ½ in the one but not the other equation.

Answers to Supplementary Problems:

18. a) 30 Ω; b) lower.

Direct Current Circuits

A. EMF

B. Combinations of resistors S-20
1. series: $V_1 + V_2 = V_{total}$; $(I_1 = I_2)$
2. parallel: $I_1 + I_2 = I_{total}$; $(V_1 = V_2)$
3. combinations

C. Resistors and Capacitors S-21,22
1. Discharging: $V_C = V_R$: $Q/C = I R$; or $Q/C = -R\, dQ/dt$
(negative sign since Q is decreasing)
2. Charging: $V_o = V_C + V_R$: $V_o = Q/C + R\, dQ/dt$

Supplementary problem (S-):

20) You are given three resistors: 2 Ω, 5 Ω, and 10 Ω.
a) Draw a diagram showing how to connect the resistors so that you get the smallest effective resistance.
b) Is your connection above purely parallel, purely series, or a combination?
c) Draw a second diagram below showing how to connect the resistors so that you get the largest effective resistance.
d) Draw a third diagram below showing how to connect the resistors so that you get some value between 2 Ω and 5 Ω for the effective resistance, and then specify what value you will get.

21) A 2.2 μF capacitor in series with a 1,000 Ω resistor is charged with a power supply of 50 volts. a) What is the maximum charge that this capacitor will store given this voltage?
b) How long a time will it take for this capacitor to store half of the maximum charge?
c) How long a time (from the switch being closed initially) will it take for this capacitor to store three fourths of the maximum charge?
d) The power supply is then disconnected, and when a switch is thrown the capacitor discharges through a 11 MΩ resistor (MΩ is a Mega-ohm = 1 million ohms). How long a time will it take to lose half of the charge that it had stored?
e) After it loses half of its charge so that it has half its charge remaining, will it have: [more than ¾, ¾, between ½ & ¾, ½, between ¼ and ½, ¼, or less than ¼] of its stored energy remaining?

22) [Extra Credit (+4): Given ten resistors each of 1 MΩ and five capacitors each of 2 μF, design a circuit with an effective RC time constant as close to 3.14 seconds as you can.]

Answers to Supplementary Problems:

21) a) 1.1×10^{-4} Coul; b) 1.53 ms; c) 3.06 ms; d) 16.8 sec. e) 1/4.