

Problem Set #5 – Chapter 24 – 71, 82, 86; Chapter 25 – 32, 34, 36, 39

Chapter 24

71. (a) The maximum potential is reached when the charge on the sphere creates an electric field large enough to break down the air. At the surface of a sphere, we have

$$E = (1/4\pi\epsilon_0)(Q/R^2) \quad \text{and} \quad V = (1/4\pi\epsilon_0)(Q/R), \quad \text{or}$$

$$V = ER = (3 \times 10^6 \text{ V/m})(1.3 \text{ m}) = \boxed{3.9 \times 10^6 \text{ V}}.$$

- (b) The increase in kinetic energy comes from the decrease in potential energy, which means the proton must go from high to low potential:

$$\Delta K = K - 0 = -\Delta U = -q \Delta V;$$

$$K = -(+1 e)(-3.9 \times 10^6 \text{ V}) = +3.9 \times 10^6 \text{ eV} = \boxed{3.9 \text{ MeV} \quad (6.2 \times 10^{-13} \text{ J})}.$$

- (c) We find the charge on the sphere from

$$V = (1/4\pi\epsilon_0)(Q/R);$$

$$3.9 \times 10^6 \text{ V} = (9 \times 10^9 \text{ C}^2/\text{N} \cdot \text{m}^2)Q/(1.3 \text{ m}), \quad \text{which gives } Q = \boxed{5.6 \times 10^{-4} \text{ C}}.$$

82. For the positron, the increase in kinetic energy comes from the decrease in potential energy:

$$K_f - K_i = -(U_f - U_i) = -e(V_f - V_i);$$

$$K_f - 0 = -e(1/4\pi\epsilon_0)(0 - e/r_i);$$

$$K_f = (e^2/4\pi\epsilon_0)(1/r_0) = (1.60 \times 10^{-19} \text{ C})^2(9 \times 10^9 \text{ C}^2/\text{N} \cdot \text{m}^2)/(6.5 \times 10^{-10} \text{ m}) =$$

$$\boxed{3.5 \times 10^{-19} \text{ J} \quad (2.2 \text{ eV})}.$$

86. Because the work done by the electric field of the dipole is independent of the path, we have

$$W_{a \rightarrow b} = q_0(V_b - V_a).$$

The initial and final points are not far from the dipole, so we find the potentials for two point charges:

$$W_{a \rightarrow b} = q_0[(1/4\pi\epsilon_0)(q/r_{b2} - q/r_{b1}) - (1/4\pi\epsilon_0)(q/r_{a2} - q/r_{a1})]$$

$$= (1/4\pi\epsilon_0)(q_0q)(1/r_{b2} - 1/r_{b1} - 1/r_{a2} + 1/r_{a1})$$

$$= (9 \times 10^9 \text{ C}^2/\text{N} \cdot \text{m}^2)(3.0 \times 10^{-6} \text{ C})(5.0 \times 10^{-6} \text{ C})[1/(0.2 \text{ m}) - 1/(0.6 \text{ m}) - 1/(0.8 \text{ m}) + 1/(0.4 \text{ m})]$$

$$= \boxed{+0.62 \text{ J}}.$$

Chapter 25

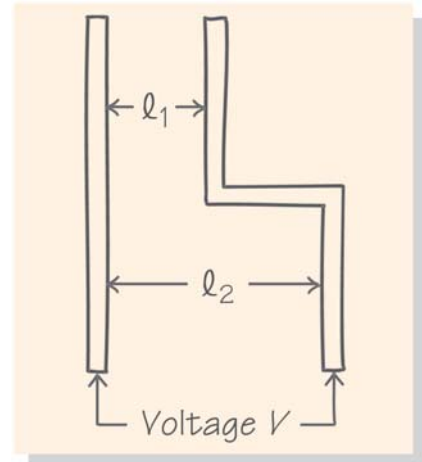
32. The voltage must be the same across both the top and bottom sections, so we have

$$E_1 = V/\ell_1 = \sigma_1/\epsilon_0,$$

which gives the charge on the top section: $Q_1 = \epsilon_0(V/\ell_1)A_1$;

$$E_2 = V/\ell_2 = \sigma_2/\epsilon_0,$$

which gives the charge on the bottom section: $Q_2 = \epsilon_0(V/\ell_2)A_2$.



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The areas are equal, $A_1 = A_2 = A/2$, and the total charge on the capacitor is

$$\begin{aligned} Q &= Q_1 + Q_2 = \epsilon_0 V (A_1/\ell_1 + A_2/\ell_2) \\ &= \epsilon_0 V (A/2) (1/\ell_1 + 1/\ell_2) = \epsilon_0 V A (\ell_1 + \ell_2) / 2\ell_1\ell_2. \end{aligned}$$

From the definition of capacitance, we have

$$C = Q/V = \frac{\epsilon_0 A (\ell_1 + \ell_2)}{2\ell_1\ell_2}.$$

This is the equivalent capacitance for 2 capacitors in parallel:

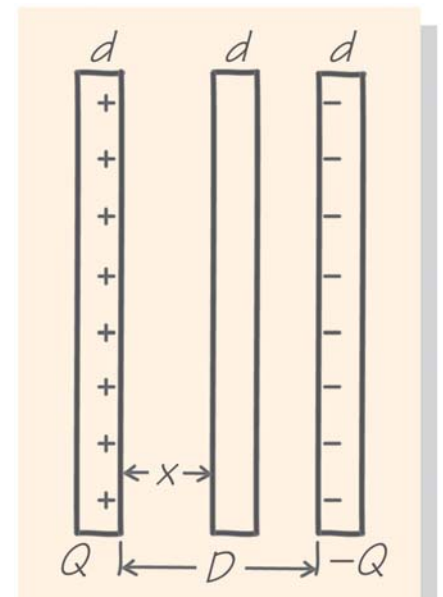
$$C = (\epsilon_0 A / 2\ell_1) + (\epsilon_0 A / 2\ell_2) = C_1 + C_2.$$

34. When the uncharged plate is placed between the two charged plates, charges will separate so that there is a charge $+Q$ on the side facing the negative plate and a charge $-Q$ on the side facing the positive plate. Thus we have two capacitors in series, with an equivalent capacitance:

$1/C = 1/C_1 + 1/C_2 = 1/(\epsilon_0 A/x) + 1/[\epsilon_0 A/(D-x-d)] = (x + D - x - d)/\epsilon_0 A$, which gives

$$C = \frac{\epsilon_0 A}{(D - d)}, \text{ independent of } x.$$

Note that this is a parallel-plate capacitor with separation $D - d$.



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36. From the circuit, we see that C_4 and C_5 are in parallel, with an equivalent capacitance

$$C_6 = C_4 + C_5 = 18 \mu\text{F} + 18 \mu\text{F} = 36 \mu\text{F}.$$

We now have four capacitors in series:

$$\begin{aligned} 1/C_{\text{equ}} &= 1/C_1 + 1/C_2 + 1/C_3 + 1/C_6 \\ &= 1/(18 \mu\text{F}) + 1/(18 \mu\text{F}) + 1/(18 \mu\text{F}) + 1/(36 \mu\text{F}), \end{aligned}$$

which gives

$$C_{\text{equ}} = \boxed{5.1 \mu\text{F}}.$$

39. To find the equivalent capacitance between a and b ,

we redraw the circuit, and see that there are two capacitors in series in the right branch:

$$1/C_1 = 1/C + 1/C, \text{ which gives } C_1 = \frac{1}{2} C.$$

For the two capacitors in parallel between d and b we have

$$C_2 = C_1 + C = \frac{1}{2} C + C = \frac{3}{2} C.$$

For the two capacitors in series between a and b we have

$$1/C_3 = 1/C + 1/C_2, \text{ which gives } C_3 = 0.6C.$$

For the equivalent capacitance, we have

$$C_{\text{equ},ab} = C + C_3 = C + 0.6C = \boxed{1.6C}.$$

To find the equivalent capacitance between a and c , we redraw the circuit, and use symmetry to simplify the circuit.

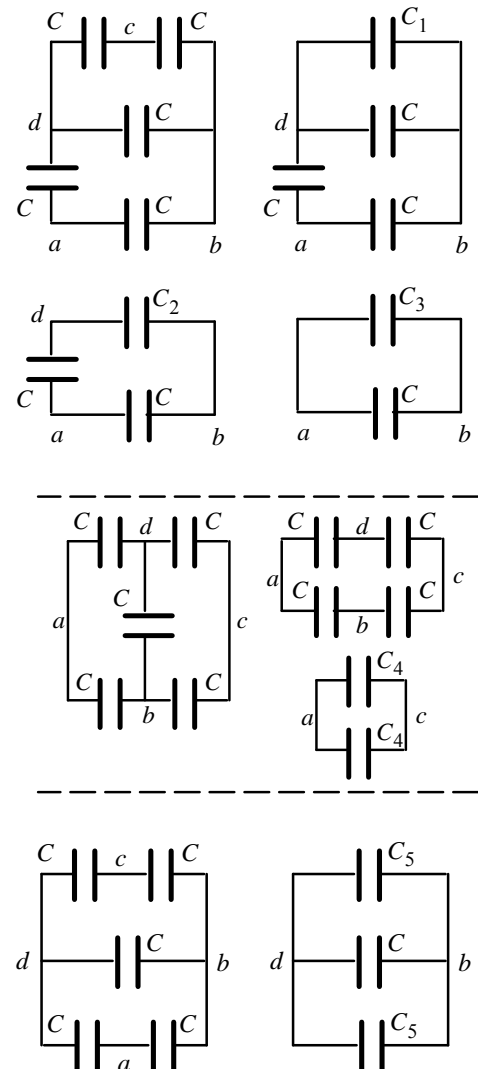
The top and bottom paths from a to c are equivalent, so we have

$$V_b = V_d,$$

which means there is no potential difference across and no charge on the middle capacitor. The circuit will not change if we remove it.

The top and bottom branches have two capacitors in series:

$$1/C_4 = 1/C + 1/C, \text{ which gives } C_4 = \frac{1}{2} C.$$



We combine these two capacitors in parallel to find the equivalent capacitance of the circuit:

$$C_{\text{equ},ac} = C_4 + C_4 = \frac{1}{2} C + \frac{1}{2} C = \boxed{C}.$$

To find the equivalent capacitance between b and d , we redraw the circuit, and see that the top and bottom paths have two capacitors in series:

$$1/C_5 = 1/C + 1/C, \text{ which gives } C_5 = \frac{1}{2} C.$$

We now have three capacitors in parallel, with equivalent capacitance

$$C_{\text{equ},bd} = C_5 + C_5 + C = \frac{1}{2} C + \frac{1}{2} C + C = \boxed{2C}.$$