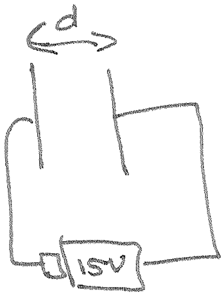
Physics 152, HW#4

Mastering Physics: 12 problems from chapters 21 and 22

One written problem

21. 77



Electrodes with 11-cm diameter ← I'm taking this to mean circular plates with radius

5.5cm = 0.055m

$d = 0.53cm = 0.0053m = 5.3\times10^{-3}m$

a) What is charge on each plate after fully charged?

When fully charged $\Delta V_c = 15V$, so use $C = \frac{Q}{\Delta V_c}$

$\Rightarrow Q = C\Delta V_c$, $C = \frac{\epsilon_0 A}{d}$ $A = \pi(0.055m)^2 = 0.0095m^2$
circle

$$C = \frac{(8.85\times10^{-12} C^2/N\cdot m^2)(0.0095m^2)}{5.3\times10^{-3}m} = 1.587\times10^{-11} F$$

Unit: $\frac{C^2}{N\cdot m^2}\cdot m^2 \cdot \frac{1}{m} = \frac{C^2}{N\cdot m} = \frac{C^2}{J}$ $F = \frac{C}{V} = \frac{C}{J/C} = C\cdot\frac{C}{J} = \frac{C^2}{J}$

$Q = C\Delta V_c = (1.587\times10^{-11}F)(15V) = 2.38\times10^{-10}C = 2.4\times10^{-10}C$

So one plate with $+2.4\times10^{-10}C$, the other plate with $-2.4\times10^{-10}C$

b) What is E?

$\Delta V_c = Ed \Rightarrow E = \frac{\Delta V_c}{d} = \frac{15V}{5.3\times10^{-3}m} = 2830\ V/m = 2800\ V/m$

c) What ΔV_c? Umm? 15V

d) Disconnect battery and Handles are used to pull plates apart to 1.8cm = 0.018m

How much charge now? → the same. There was nowhere for charges to go.

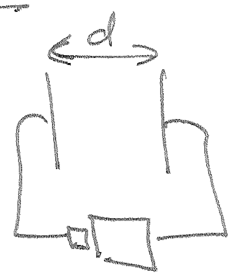
e) What is new field strength? → the same

$E = \frac{Q}{\epsilon_0 A}$, No change in Q or A so same 2800V/m

f) What is ΔV_c? → this has changed.

$\Delta V_c = Ed = (2800V/m)(0.018m) = 50.4V = 50V$

21.78



13V

Plates with 10-cm diameter $\Rightarrow$ radius = 5cm = .05m

$d = 0.5cm = 0.005m = 5 \times 10^{-3} m$

a) What is charge on each plate?

$C = \frac{Q}{\Delta V_c}$ when fully charged $\Delta V_c = \Delta V_B = 13V$

$\Rightarrow Q = C \Delta V_c$ $\quad C = \frac{\epsilon_0 A}{d}$ $\quad A = \pi (0.05m)^2 = 0.00785 m^2$

$$\Rightarrow C = \frac{(8.85 \times 10^{-12} C^2/N \cdot m^2)(0.00785 m^2)}{5 \times 10^{-3} m} = 1.39 \times 10^{-11} F = 1.4 \times 10^{-11} F$$

(see previous solution for units)

$Q = C \Delta V_c = (1.4 \times 10^{-11} F)(13V) = 1.8072 \times 10^{-10} C = 1.8 \times 10^{-10} C$

So one plate with $+1.8 \times 10^{-10} C$, the other with $-1.8 \times 10^{-10} C$

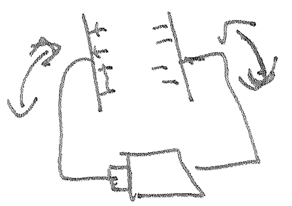
b) [illegible] $\Delta V_c = Ed \Rightarrow E = \frac{\Delta V_c}{d} = \frac{13V}{5 \times 10^{-3} m}$

$\Rightarrow E = 2600 V/m$

c) $\Delta V_c = 13V$ As used many times now.

d) Battery remains attached while plates are pulled apart to $1.8cm = 0.018m$

In this case, the charges have an escape route through the battery.



Either more electrons added to ~~positive~~ negative plate by removing from positive plate, or

electrons removed from negative plate and put onto positive plate.

First scenario increases charge on EACH plate, the 2ND scenario decreases charge.

To find out, we use the fact that since the battery remains attached, it will ensure that $\Delta V_C = 13V$ still.

C has changed, $C = \frac{\epsilon_0 A}{d} = \frac{(8.85\times10^{-12}\,C^2/Nm^2)(0.00785\,m^2)}{0.018m}$

$\Rightarrow C = 3.862\times10^{-12}F$

So $Q = C\Delta V_c = (3.862\times10^{-12}F)(13V) = 5.02\times10^{-11}C \approx 5\times10^{-11}C$

So charge decreased, but EACH plate still has the same

i.e. $+5\times10^{-11}C$ and $-5\times10^{-11}C$

e) E will also change here.

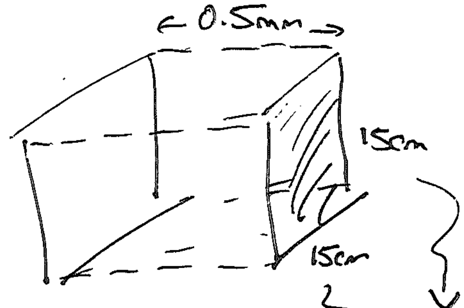
It's probably easiest to use $\Delta V_c = Ed \Rightarrow E = \frac{\Delta V_c}{d}$

Since $\Delta V_c = 13V$, $E = \frac{13V}{0.018m} = 722.2 V/m \approx 720 V/m$

↑ pulling plates apart decreased E

F) $\Delta V = 13V$ still as we used many times.

21.83



MAX Electric field:

$E_{MAX} = 3MV/m$ for AIR

$E_{MAX} = 60MV/m$ for TEFLON

$15cm \times \frac{m}{100cm} = 0.15m$

a.) What is MAX Energy Stored in Air-Filled Capacitor?

Since we always assume Capacitors create a uniform field we can use $\Delta V_C = Ed$. Using $d = 0.5mm$ and $E = E_{MAX}$ will give us the largest ΔV_C possible. Then we can find the Capacitance from $C = \frac{\varepsilon_0 A}{d}$

Then $U = \frac{1}{2} C \Delta V_C^2$ will give us the maximum Energy stored.

For the Air Capacitor: $E = 3MV/m = 3\times10^6 V/m$, $d = 0.5mm \times \frac{m}{1000mm} = 5\times10^{-4}m$

$\therefore \Delta V_C = (3\times10^6 V/m)(5\times10^{-4}m) = 1500V$

$A = (0.15m)(0.15m) = 0.0225m^2 \therefore C = \frac{(8.85\times10^{-12} C^2/N\cdot m^2)(0.0225m^2)}{5\times10^{-4}m} = 3.9825\times10^{-10}F$

So $U = \frac{1}{2}(3.9825^{-10}F)(1500V)^2 = 4.48\times10^{-4}J = 4.5\times10^{-4}J$

Unit: $F\cdot V^2 = \frac{C}{V}\cdot V^2 = C\cdot V = C\cdot J/C = J$

b.) With TEFLON?

Now $E_{MAX} = 60MV/m = 60\times10^6 V/m = 6\times10^7 V/m$

So $\Delta V_C = (6\times10^{7}\,V/m)(5\times10^{-4}\,m) = 30000\,V$

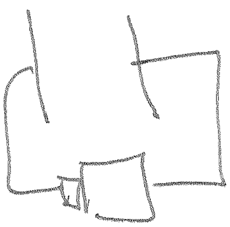
<u>But</u> THE CAPACITANCE IS ALSO LARGER!

$C = \kappa C_0$ $\kappa = 2$ FOR TEFLON

$\Rightarrow C = 2(3.9825\times10^{-10}\,F) = 7.965\times10^{-10}\,F$

So $U = \frac{1}{2}(7.965\times10^{-10}\,F)(30000\,V)^2 = 0.358425\,J = \underline{0.36\,J}$

21.85



370V

So $\Delta V_c = 370V$ after charging

discharge takes $12\mu s = 12\times10^{-6}s = 1.2\times10^{-5}s$

Power : $P_{AV} = 11$ watt

$$\text{Power} = \frac{\text{Work}}{\Delta t} = \frac{-\Delta U_c}{\Delta t}$$

Note: $-\Delta U_c$ since capacitor's potential energy is used to create Flash

After Flash Capacitor HAS no energy left $\Rightarrow \Delta U_c = 0 - U_c = -U_c$

(initial)

$$\Rightarrow P_{av} = \frac{-(-U_c)}{\Delta t} = \frac{+U_c}{\Delta t} \Rightarrow U_c = P_{AV}\Delta t = (11\text{ watt})(1.2\times10^{-5}s)$$

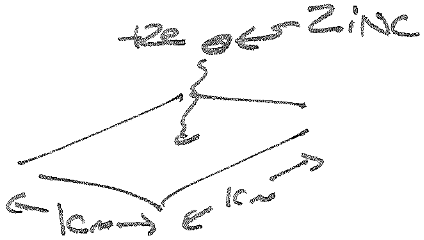
$$\Rightarrow U_c = 1.32\times10^{-4}J$$

unit: $\text{watt}\cdot s = \frac{J}{s}\cdot s = J$

$$U_c = \frac{1}{2}C\Delta V_c^2 \Rightarrow C = \frac{2U_c}{\Delta V_c^2} = \frac{2(1.32\times10^{-4}J)}{(370V)^2} = 1.928\times10^{-9}F$$

$$= 1.9\times10^{-9}F$$

Electroplating



WANT thickness of 140nm $= 140 \times 10^{-9}$m

$= 1.4 \times 10^{-7}$m

$I = 1.4$mA $= 1.4 \times 10^{-3}$A

$I = \frac{\Delta q}{\Delta t} \Rightarrow \Delta t = \frac{\Delta q}{I}$ ← TOTAL CHARGE Deposited ON SURFACE

EACH ZINC ATOM HAS Charge $+2e = 2(1.6 \times 10^{-19}C) = 3.2 \times 10^{-19}C$

So FIND # OF ATOMS

Zinc's ATOMIC MASS is 65.4 ⇒ 65.4g of zinc has

$N_A = 6.02 \times 10^{23}$ ATOMS (Avagadro's #)

Density = 7140 kg/m³, So Volume of Zinc deposited:

$V = (.01m)(.01m)(1.4 \times 10^{-7}m) = 1.4 \times 10^{-11}m^3$

$1.4 \times 10^{-11}m^3 \times \frac{7140kg}{m^3} = 9.996 \times 10^{-8}kg \times \frac{1000g}{kg} = 9.996 \times 10^{-5}g \times \frac{6.02 \times 10^{23} \text{Atom}}{65.4g}$

$= 9.2 \times 10^{17}$ atoms $\times \frac{3.2 \times 10^{-19}C}{\text{atom}} = 0.294C$

$\Delta t = \frac{0.294C}{1.4 \times 10^{-3}A} = 210s$

22.15

$\mathcal{E} = 6.5\,V \quad I = 4\,mA = 4\times10^{-3}\,A$

$\Delta t = 4.1\,\text{hour} \times \frac{3600\,s}{h} = 14760\,s$

a) How much charge has passed through a cross section?

$I = \frac{\Delta q}{\Delta t} \Rightarrow \Delta q = I\Delta t = (4\times10^{-3}A)(14760\,s) = 59\,C$

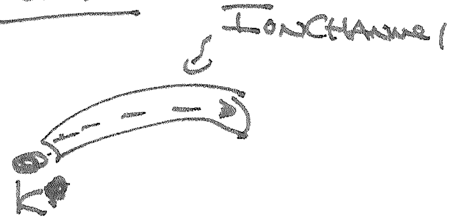
b) How much work?

$\Delta V = \frac{W}{q} \Rightarrow W = q\Delta V$. So Battery moves total

charge $q = \Delta q = 59\,C$. through $\Delta V = 6.5\,V$

This gives $W = (59\,C)(6.5\,V) = 383.76\,J = 380\,J$

22.48



$I = 1.8\,pA = 1.8\times10^{-12}A$

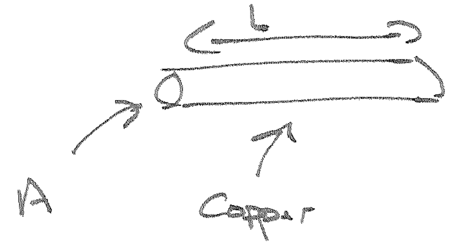
$\Delta t = 1ms = 1\times10^{-3}s$

$I = \frac{\Delta q}{\Delta t} \Rightarrow \Delta q = I\Delta t = (1.8\times10^{-12}A)(1\times10^{-3}s) = 1.8\times10^{-15}C$

$K^+ \Rightarrow$ EACH potassium ion HAS SAME charge AS A proton

$\Rightarrow \frac{1.8\times10^{-15}C}{1.6\times10^{-19}C/ION} = 11250$ IONS $= 11000$

Science Olympics



2g of Copper $\Rightarrow 2g \times \frac{1kg}{1000g} = 0.002\,kg$

Want $R = 1.1\,\Omega$

$R = \frac{\rho L}{A}$ For Copper $\rho = 1.7\times10^{-8}\,\Omega\cdot m$

Copper has density $8900\,kg/m^3 \Rightarrow 0.002\,kg \times \frac{1}{8900\,kg/m^3} = 2.247\times10^{-7}\,m^3$

For A cylinder Volume $= AL \Rightarrow A = \frac{Volume}{L} = \frac{2.247\times10^{-7}\,m^3}{L}$

Area of base = Cross-sectional Area

$\therefore R = \frac{\rho L}{\frac{2.247\times10^{-7}\,m^3}{L}} = \rho L \cdot \frac{L}{2.247\times10^{-7}\,m^3} = \frac{\rho L^2}{2.247\times10^{-7}\,m^3}$

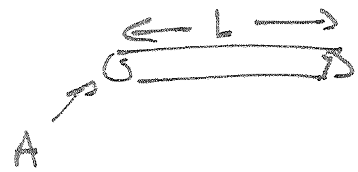
$\therefore L^2 = \frac{(1.1\,\Omega)(2.247\times10^{-7}\,m^3)}{1.7\times10^{-8}\,\Omega\cdot m} = 14.54\,m^2 \Rightarrow L = \sqrt{14.54\,m^2} = 3.8\,m$

b)

Diameter: $A = \pi r^2 = \frac{2.247\times10^{-7}\,m^3}{3.8\,m} = 5.89\times10^{-8}\,m^2 \Rightarrow r = \sqrt{\frac{5.89\times10^{-8}\,m^2}{\pi}} = 1.37\times10^{-4}\,m = 0.137\,mm \Rightarrow d = 2\times r = 0.27\,mm$

circle

22.20



$R = 1.9\times10^{-2}\,\Omega$

Wire stretched to twice its length but Volume unchanged.

$$\text{Volume} = AL \quad \Rightarrow \quad A_iL_i = A_fL_f \quad \Rightarrow A_iL_i = A_f(2L_i)$$

$$\Rightarrow A_f = \frac{A_i L_i}{2 L_i} = \frac{1}{2}A_i$$ ← to keep Volume the same we have to cut Area in half.

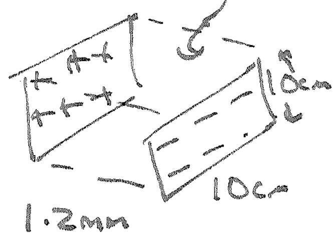
$$R = \rho\frac{L}{A} \Rightarrow R_i = \rho\frac{L_i}{A_i}, \quad R_f = \rho\frac{L_f}{A_f}$$ } SAME Material, so SAME ρ

$$R_f = \rho\frac{(2L_i)}{\frac{1}{2}A_i} = \rho\frac{L_i}{A_i}\left(\frac{2}{1/2}\right) = R_i(4)$$ ← Quadrupling Resistance

$$\therefore \; R_f = 1.9\times10^{-2}\,\Omega(4) = 7.6\times10^{-2}\,\Omega = 0.076\,\Omega$$

22.47

Air! $\rho = 3\times10^{13}\,\Omega\cdot m$

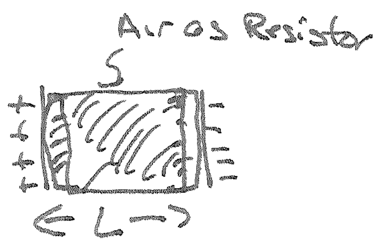


$\Delta V_C = 250V$, what FRACTION of CHARGE ESCAPES in 1min?

$\Rightarrow \Delta t = 1min = 60s$

I DON'T think Air is ohmic, but we'll pretend it is

So $\Delta V_R = IR$ where $\Delta V_R = \Delta V_C = 250V$



So Potential at ONE END OF Resistor is V_+ the other is V_- $\Rightarrow \Delta V_R = V_+ - V_- = \Delta V_C$

$\Rightarrow I = \frac{\Delta V_R}{R}$ $R = \rho\frac{L}{A}$ $L = d$ = distance between plates

$L = 1.2mm = 1.2\times10^{-3}m$

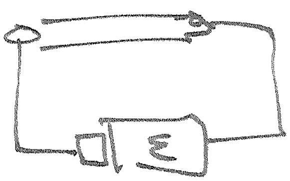
$A = (10cm)(10cm) = (.01m)(.01m) = 1\times10^{-4}m^2$

$\therefore R = \frac{(3\times10^{13}\,\Omega\cdot m)(1.2\times10^{-3}m)}{1\times10^{-4}m^2} = 3.6\times10^{14}\,\Omega$

$I = \frac{250V}{3.6\times10^{14}\,\Omega} = 6.944\times10^{-13}A$

$I = \frac{\Delta q}{\Delta t} \Rightarrow \Delta q = I\Delta t = (6.944\times10^{-13}A)(60s) = 4.167\times10^{-11}C$

22.54



Blood Vein → looking a lot like a wire!

5cm long, 1.5mm diameter ⇒ radius $r = 0.75mm = .75\times10^{-3}m = 7.5\times10^{-4}m$

$\mathcal{E} = 8.5V \quad I = 240\mu A = 240(1\times10^{-6}A) = 2.4\times10^{-4}A$

Again, I don't think blood is ohmic but...

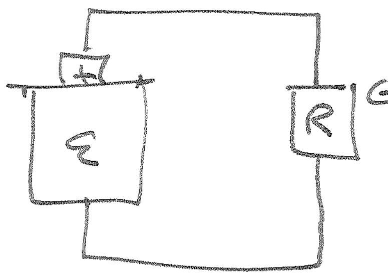
$\Delta V_R = IR \Rightarrow R = \frac{\Delta V_R}{I}$ Since attaching wires have zero resistance, $\Delta V_R = \mathcal{E}$

$\therefore R = \frac{8.5V}{2.4\times10^{-4}A} = 35416.7\Omega$

$R = \frac{\rho L}{A} \Rightarrow \rho = \frac{RA}{L} = \frac{R\pi r^2}{L} = \frac{(35416.7\Omega)\pi(7.5\times10^{-4}m)^2}{.05m}$ (circle → πr^2)

$\Rightarrow \rho = 1.25\Omega\cdot m = 1.3\Omega\cdot m$

Resistance of a Heater



$\mathcal{E} = 120V$

$P_R = 1500 \text{watt}$ ← Power used by Heater

a) How much Current?

$P_R = I \Delta V_R$ since Heater only Resistor in Circuit

$\Delta V_R = \mathcal{E} = 120V \Rightarrow I = \frac{P_R}{\Delta V_R} = \frac{1500\text{watt}}{120V} = 12.5A$

Unit: $\frac{\text{watt}}{V} = \frac{J/s}{J/C} = \frac{J}{s} \cdot \frac{C}{J} = C/s = A$

b) What is Resistance?

We can do this many ways! $\Delta V_R = IR$ or $P_R = \frac{\Delta V_R^2}{R}$ or $P_R = I^2 R$

How about $R = \frac{\Delta V_R}{I} = \frac{120V}{12.5A} = 9.6\Omega$

c) How long to raise Temp of Air by 10°C?

Assume room is 3m × 5m × 8m, $C_{air} = 1006 \frac{J}{kg \cdot C°}$, density $= 1.2 \frac{kg}{m^3}$

↑ specific heat

Heat Review! Usually heat is called Q. Stupid English!

So let's just say: Heat $= mc\Delta T$

Heat is coming from Power dissipated by Heater

$$P_R = \frac{\text{Heat}}{\Delta t} \Rightarrow \text{Heat} = P_R \Delta t$$

$P_R \Delta t = mc\Delta T$ m = mass, which we get from the

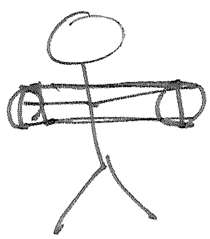
density, Volume of room $= (3m)(5m)(8m) = 120m^3 \times \frac{1.2kg}{m^3} = 144kg$

$$\therefore P_R \Delta t = mc\Delta T \Rightarrow \Delta t = \frac{mc\Delta T}{P_r} = \frac{(144kg)(1006 J/kg \cdot C°)(10°C)}{1500 watt\ J/s}$$

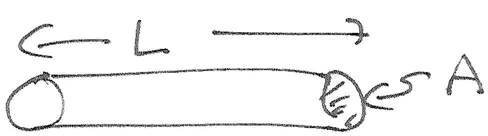
$$\Rightarrow \Delta t = 965.76s \times \frac{min}{60s} = 16.096 min = 16.1 min$$

Written Question #1

a) Yes, there's a difference between voltage and current. The voltage is the "push" on the charges while the current is the ~~actual~~ amount of charges that actually move. ~~A~~ The relation between the two depends on the resistance. So if a person with very large resistance is subjected to a very large voltage, only a small amount of current will flow. If the resistance is large enough to make the current less than 100mA, then they will survive. (Way less than 100mA to be safe!)

b) Person as cylinder: 

$R = \rho \frac{L}{A}$



$\rho = 5\,\Omega \cdot m$

I measure my hand-to-hand length to be 1.85 m. The diameter of my arm is about 10cm ⇒ radius of 5cm = 0.05m (Your numbers will probably be different!) ∴ $L = 1.85m$

$A = \pi r^2 = \pi (0.05m)^2 = 0.00785\,m^2$

So my Resistance is $R = \frac{(5\,\Omega\cdot m)(1.85m)}{0.00785m^2} = 1177\,\Omega$

$= 1200\,\Omega$

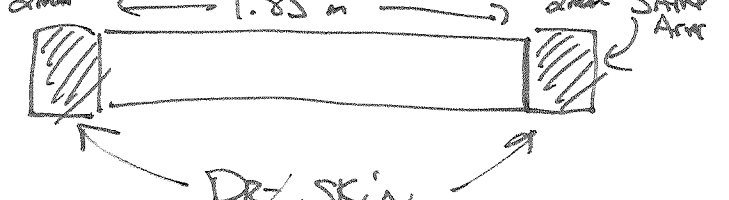
↑ I wouldn't trust more than 2 sig figs

c.) What ΔV_R for lethal $I = 100mA = 100(10^{-3})A = 0.1A$

$\Delta V_R = IR = (0.1A)(1200\,\Omega) = \underline{\underline{120V}}$ ← your answer will differ

Note: A typical US outlet has a voltage of 120V! So BE Careful.

d.) Add in Dry skin on ends:



So $R = \frac{\rho L}{A} \Rightarrow$

$R = \frac{\rho_1 L_1}{A} + \frac{\rho_2 L_2}{A} + \frac{\rho_3 L_3}{A}$

Since all 3 pieces have same Area $A = 0.00785m^2$

$\rho_1 = \rho_3 = 40000\,\Omega\cdot m, \quad L_1 = L_3 = 2mm = 2\times10^{-3}m$

$\rho_2 = 5\,\Omega\cdot m, \quad L_2 = 1.85m$

So THE MIDDLE piece is $1200\,\Omega$ Again.

$$\frac{\rho_1 L_1}{A} = \frac{(40000\,\Omega\cdot m)(2\times 10^{-3}\,m)}{0.00785\,m^2} = 10191\,\Omega = 10\,200\,\Omega$$

$$\Rightarrow R = 10200\,\Omega + 1200\,\Omega + 10300\,\Omega = 21600\,\Omega$$

(YOU CAN ALSO DO this by TREATING this as 3 RESISTORS IN SERIES AND FINDING the EQUIVALENT RESISTANCE. SINCE that MATERIALS is in Chapter 23, I did this in the slightly longer WAY shown here.)

e.) $\Delta V_R = IR = (0.1\,A)(21600\,\Omega) = 2160\,V$

Much higher than outlets! I feel SAFE AGAIN.