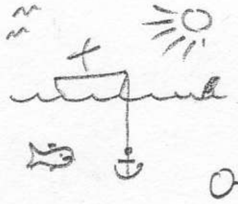
Current Electricity ~ Resistivity + Drift



AS Phys.

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

$I = nAve$

data:- $e = 1.6 \times 10^{-19}$ C

$\rho_{Cu} = 1.6 \times 10^{-8}$ Ωm

$\rho_{nichrome} = 1.1 \times 10^{-6}$ Ωm

$n_{Cu} = 5 \times 10^{29}$ m^{-1}

$n_{nichrome} = 2 \times 10^{29}$ m^{-1}

Curly Fries £1.10 $portion^{-1}$

$\rho_{Al} = 2.5 \times 10^{-8}$ Ωm

$n_{Al} = 4 \times 10^{29}$ m^{-1}

A Starters + warm ups

1. What is the cross-section area of a wire 0.18 mm diameter? (2)
2. What is the diameter of a wire with cross section area of 2.4×10^{-7} m^2? Give answer in mm and m. (3)

☆ Answers at the bottom of page 2 - Upside down.

You *must* be able to handle "d" and "A".

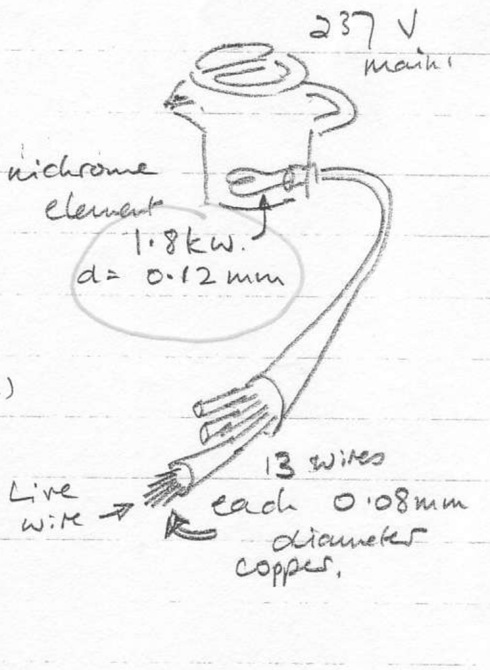
3 (a) A reel of copper wire is labelled "1.8 Ohms/metre." What is its diameter? (4)

Harder (b) You want copper wire with half the resistance/metre. What area should it have? ... what diameter? (2)

☆ Can you do this *without* re-doing the whole calculation?

B: Time for a Cuppa.

4 (a) This question is about the kettle - 2.2kW power, running off 237 V mains. The element is 0.22 mm diameter nichrome wire, what length should it be? (5)



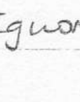
Harder (b) Suppose you want a "Hi-Speed" version of the kettle, with twice the power. How long should the nichrome wire be for this? (2)

(c) What is the drift velocity of electrons in the element, when the kettle is on? (2)

(☆ Ignore the fact that mains is ac!)

5. This question is about the copper wires in the mains lead.

(a) The live wire has 13 copper wires each of 0.08 mm diameter. What is the total cross section area? (3)



The kettle's power is still 1.8 kW!

(b) What is the current to the kettle? (2)

5 continued...

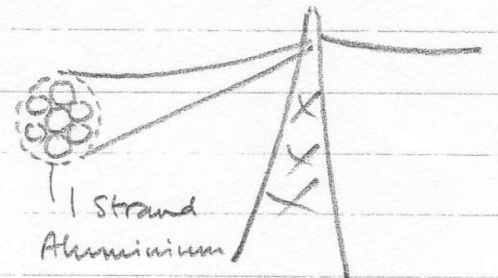
(c) What is the drift velocity of electrons in the live copper wire? (2)

(d) When the kettle is switched on, the mains cable gets slightly warm – why? (2)

(e) What is the power output of 1 m of the live wire? (4)

C Power to the People

6. A high voltage cable is made of 7 strands of Aluminium, each strand is 8 mm diameter



(a) What is the resistance of 1 km of cable? (4)

(b) The cable delivers 1.2 MW of power at 440 kV to a small town in the East Midlands. What is the current in the cable? (3)

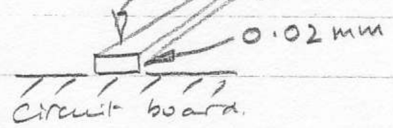
(c) What is the electron drift velocity? (ignore it's ac!) (2)

(d) To prevent overheating, the Power Supply company set a "speed limit" for the drift velocity of 50 nm/s * How many strands of 8 mm diameter are needed to keep the drift velocity below this limit? (4)

* 1 nm = 1 nanometre = 1×10^{-9} m.

D. A Casio Calculator Conclusion...

7. My old Casio calculator says on the back "3.0 V dc, 0.0004 W" Current is fed to the circuit along the copper track shown ⟹.



(a) What is the track resistance? (4)

(b) What is the electron drift velocity? (2)

1/2 2/3 3/6 4/9 5/13 6/13 7/6

Answers: Q.1 $A = 2.54 \times 10^{-8}\ m^2$ (3 s.f.)
Q.2 $d = 5.5 \times 10^{-4}\ m = 0.55$ mm

TMN Sept '04.

Current Elec - Resistivity + Drift — Answers — AS Physics — 1/of 2

A. 1. $A = \pi r^2$ ... so $r = \frac{0.18\times10^{-3}}{2}$ m $= 0.09\times10^{-3}$ m (1)

so $A = \pi \times (0.09\times10^{-3})^2 = 2.54\times10^{-8}$ m² (1) 3 s.f. /2

2. $A = 2.4\times10^{-7} = \pi r^2$ so $r^2 = 2.4\times10^{-7}/\pi = 7.64\times10^{-8}$ so $r = 2.76\times10^{-4}$ m (1)

so diameter $d = 5.53\times10^{-4}$ m (1) $= 0.553$ mm. (1) (3 s.f.) /3

3 (a) "1.8 Ohms/m" ... so use $R = \rho l/A$ and then $1.8 = \frac{1.6\times10^{-8}\times 1}{A}$ (1)

So $A = 1.6\times10^{-8}/1.8 = 8.89\times10^{-9}$ m² (1) $= \pi r^2$

so $r^2 = 8.89\times10^{-9}/\pi = 2.83\times10^{-9}$ m² and then $r = 5.32\times10^{-5}$ m (1)

So diameter $d = 1.06\times10^{-4}$ m (1) (= 0.1 mm - thin, but realistic.) /4

(b) Option A ... do the calculation again ...

$R = 0.9\ \Omega$/m ... so $A = 1.6\times10^{-8}/0.9 = 1.78\times10^{-8}$ m²

so $r^2 = 5.66\times10^{-9}$ m² ... so $r = 7.52\times10^{-5}$ m ... so $d = 1.50\times10^{-4}$ m /2

or ... think ... $R = \rho l \times 1/A$ so $R \propto 1/A$

so if R is halved then Area A is doubled so $A = 1.78\times10^{-8}$ m²

and then ... $A = \pi r^2$ so if A is doubled then r^2 is doubled so r is $\times\sqrt{2}$

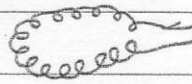
... so d is $\times\sqrt{2}$ bigger ... so d new is $1.06\times10^{-4}\times\sqrt{2} = 1.50\times10^{-4}$ m (hmm....)

/2

B. 4 (a) $P = IV = V^2/R$ so $R = V^2/P$ (1) $= 237^2/2{,}200 = 25.5\ \Omega$ (1) (or go via $P = IV$ and $R = V/I$)

Now ... $R = \rho l/A$ — we need A .... $= \pi\times\left(\frac{0.22\times10^{-3}}{2}\right)^2 = 3.80\times10^{-8}$ m² (1)

so $l = \frac{RA}{\rho} = \frac{25.5\times3.8\times10^{-8}}{1.1\times10^{-6}}$ (1)

$= 0.88$ m (1) (hmm ... a sensible figure ... coiled  /5

(b) hi-speed kettle

Option A: do it again $P = 4.4$ kW so $R = 12.8\ \Omega$

Area A is the same ... so $l = RA/\rho = \frac{12.8\times3.80\times10^{-8}}{1.1\times10^{-6}} = 0.44$ m (2)

Option B ... think $R \propto 1/P$ so $2\times P \Rightarrow \frac{1}{2}R$

$l \propto R$ ... so $\frac{1}{2}R$ means $\frac{1}{2}l = 0.88/2$ m $= 0.44$ m (2)

(c) $I = nAve$ so $v_{drift} = I/nAe$ (1) (we need $I = P/V = 9.28$ A (1)

$= 9.28/2\times10^{29}\times3.80\times10^{-8}\times1.6\times10^{-19} = 7.6\times10^{-3}$ m/s

$= 7.6$ mm/s (1)

(sensible! /3

5 (a) Total area $A = 13\times\pi r^2$ (1) each strand $= 13\times\pi\times\left(\frac{0.08\times10^{-3}}{2}\right)^2$ (1) $= 6.53\times10^{-8}$ m² (1) /3

(b) $I_{kettle} = P/V = 2200/237$ (1) $= 9.28$ A (1) /2

TW
oct '04

Hmm ... I did this in part (c)! 

⇒ page 2

Q 5 continued...

(c) use $I = nAve$ so $v_{drift} = I/nAe = 9.28 / 5\times10^{29} \times 6.53\times10^{-8} \times 1.6\times10^{-19}$ ①

$= 1.78\times10^{-3}$ m/s $=$ 1.8 mm/s ① /2

(d) The copper wire has a small resistance.... the drifting electrons collide with the atoms and set them vibrating... heat them up. /2

(e) $P = IV = I^2R$. ... what is R of 1m of live copper cable?

$R = \rho l/A = 1.6\times10^{-8} \times 1 / 6.53\times10^{-8}$ ① $= 0.245$ ① Ohms

So Power output $P = (9.28)^2 \times 0.245$ ① $=$ 21 ① watts /4

6. (a) $R = \rho_{Al}\frac{l}{A}$ ① .... But first find $A = 7\times\pi r^2 = 7\times\pi\times(4\times10^{-3})^2 = 3.52\times10^{-4}$ ① m^2

So $R = 2.5\times10^{-8} \times 1000 / 3.52\times10^{-4}$ ① $=$ 0.071 ① Ohms /4

(b) Think... $P = IV$ so $I = P/V$ ① $= 1.2\times10^6 / 440\times10^3 = 2.73$ ① A. /3

(c) $I = nAve$ so $v_{drift} = \frac{I}{n_{Al}Ae} = \frac{2.73}{4\times10^{29} \times 3.52\times10^{-4} \times 1.6\times10^{-19}}$ ① $= 1.21\times10^{-7}$ ① m/s /2

(d) $v_{drift\,max} = 50$ nm/s $= 50\times10^{-9}$ m/s ①

So $A_{max} = I / n\,v_{max}\,e$

$= 2.73 / 4\times10^{29} \times 50\times10^{-9} \times 1.6\times10^{-19} = 8.53\times10^{-4}$ ① m^2

1 strand of Al wire has area $\pi r^2 = \pi\times(4\times10^{-3})^2 = 5.03\times10^{-5}$ ① m^2

So the number of strands needed is $8.53\times10^{-4} / 5.03\times10^{-5} = 16.97$

$=$ 17 strands ① /4

7. $R = \rho l/A$ find A = width + height $= 1.5\times10^{-3} \times 0.02\times10^{-3}$ ① $=$ 3×10^{-8} m^2 ①

So R track $= 1.6\times10^{-8} \times 10\times10^{-3} / 3\times10^{-8}$ ①

$= 5.33\times10^{-3}$ ① Ohms /4

(b) $I = nAve$ so $v_{drift} = I/nAe$ find $I = P/V = \frac{0.0004}{3} = 1.33\times10^{-4}$ A ①

$= \frac{1.33\times10^{-4}}{5\times10^{29}\times3\times10^{-8}\times1.6\times10^{-19}}$ ①

$=$ 5.6×10^{-8} m/s ① /3

Q:...	1	2	3	4	5	6	7	Total
	/2	/3	/6	/10	/13	/13	/7	/54

TJN

Oct '04