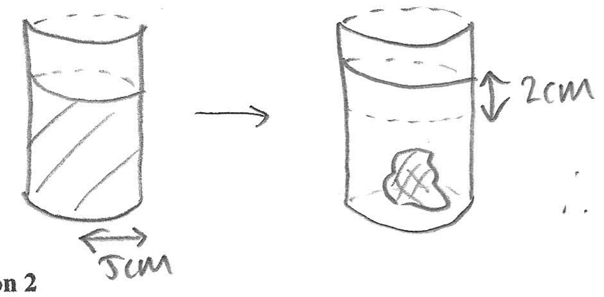
WRITE ON THIS PAPER UNLESS TOLD OTHERWISE. **CLEARLY SHOW ALL WORKINGS!** PAY ATTENTION TO NEATNESS AND ORGANIZATION. HAND IT IN ON TIME. HAVE A GO EVEN IF AT FIRST YOU CAN'T SPOT THE ANSWER!

NAME: Dr French SET: .... DATE: ....

Measurement/Density/Units

Question 1

A meteorite is placed in a cylinder of water. The radius of the cylinder is 5cm. When immersed the height of the water rises by 2cm. Meteorites are known to have densities between 3 and 8 g/cm^3. Calculate the range of masses you expect the meteorite to have.



Density $\rho = M/V$

$\therefore \boxed{M = \rho V}$

$V = \pi \times 5^2 \times 2$

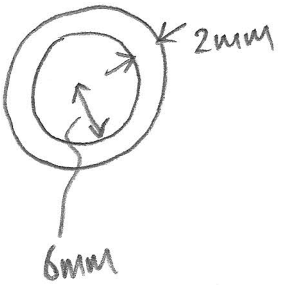
$V = 50\pi \text{ cm}^3$

$\therefore 150\pi \text{ g} < M < 400\pi \text{ g}$

$\boxed{471 \text{ g} < M < 1260 \text{ g}}$

Question 2

Samples of a rare meteorite can be bought for £500 per gram. A ring is to be fashioned. The inner radius is 6mm, the ring thickness is 2mm and the height of the ring is 5mm. If the density is 7g/cm^3, calculate (i) the mass of the ring and (ii) the cost of materials



Volume of ring is $(\pi \times 8^2 - \pi \times 6^2) \times 5$

$= \boxed{140\pi \text{ mm}^3}$

$\therefore 1 \text{ mm} = 10^{-1} \text{ cm} \quad \therefore 1 \text{ mm}^3 = 10^{-3} \text{ cm}^3$

So $140\pi \text{ mm}^3 = \frac{140\pi}{1000} \text{ cm}^3 \quad \therefore M = \rho V$

$= \frac{980\pi}{1000} = \boxed{3.08 \text{ g}}$

So cost is $\boxed{£1539}$

Question 3

An electrical signal is to be transmitted along a 100km cable between Winchester and London. The signal travels at one fifth of the speed of light in a vacuum, which is $c = 2.998 \times 10^8 \text{ms}^{-1}$. Calculate the travel time in micro-seconds (μs)

At constant speed: $\frac{1}{5}c = \frac{100 \times 10^3 \text{ m}}{t} \quad \therefore t = \frac{100 \times 10^3}{2.998 \times 10^8} \times 5$

$t = 1.668 \times 10^{-3} \text{ s} = \boxed{1668 \ \mu s}$

Question 4

1 inch = 2.54cm, 1 month = 365/12 days

A nerve can re-grow at a rate of about 1 inch per month. Calculate this speed in ms^{-1}, writing your answer in standard form to 2.s.f.

$v = \frac{1 \times 2.54 \times 10^{-1} \text{ m}}{\frac{365}{12} \times 24 \times 3600 \text{ s}} = \boxed{9.7 \times 10^{-8} \text{ ms}^{-1}}$

(ie about 1000 atoms per second)

$\uparrow 10^{-10}$ m

Question 5

According to a report in 2017, the European Union wastes about 88 million tonnes of food a year. If the average density of food products ~~as~~ is 25% higher than water, and water has a density of 1000kg/m^3, calculate the volume of food wasted.

Please express your answer in terms of number of filled swimming pools. (Dimensions are 25m x 10m x 2m).

$\rho = \frac{M}{V}$

$\therefore V = \frac{M}{\rho}$

$V = \frac{88 \times 10^6 \times 10^3 \text{ kg}}{1.25 \times 1000}$

$= 7.04 \times 10^7 \text{ m}^3$

$\therefore$ in swimming pools this is $\frac{7.04 \times 10^7}{25 \times 10 \times 2} = \boxed{140{,}800}$

which is a lot!

Question 6

1 electron-volt (eV) is about 1.602×10^{-19}J. An alpha particle of mass 6.64×10^{-27}kg is accelerated to 10% of the speed of light. Calculate its *kinetic energy* in electron-volts. Note the speed of light is $c = 2.998 \times 10^{8}\text{ms}^{-1}$.

$E = \frac{1}{2}mv^2$ (Assume Classical physics!)

$E = \frac{1}{2} \times 6.64 \times 10^{-27} \times (0.1 \times 2.998 \times 10^8)^2$

$E = 2.98 \times 10^{-12}$ J

$\therefore$ in eV this is $\frac{2.98 \times 10^{-12}}{1.602 \times 10^{-19}}$

$= \boxed{1.86 \times 10^7 \text{ eV}}$ or $\boxed{18.6 \text{ MeV}}$

Question 7

A lake of uniform depth of 10m ~~deep~~ evaporates at a rate of 200mm per year. If no water enters the lake via rainfall or rivers, calculate how long (in years) it will take for the lake to become dry.

$\# \text{ years} = \frac{10 \text{ m}}{200 \times 10^{-3} \text{ m/year}} = \boxed{50 \text{ years}}$

Question 8

On average, a person in the UK requires about ~~200,000~~ 0.72 billion joules of energy every ~~hour~~ day to live a comfortable modern life. If a nuclear power station has a generating capacity of 2GW (i.e. 2×10^9 joules per second), calculate the number of nuclear power stations the UK needs, if all of its energy needs are supplied in this way. (Note the UK has15 active reactors as of 2017). and a population of about 65 million.

$\underbrace{0.72 \times 10^9 \times 65 \times 10^6}_{\text{Energy / day in UK needed}} = \underbrace{n \times 2 \times 10^9 \times 3600 \times 24}_{\text{Energy / day for one power Station}}$

$\therefore n = \frac{0.72 \times 10^9 \times 65 \times 10^6}{2 \times 10^9 \times 3600 \times 24}$

$= \boxed{271}$

Kinematics

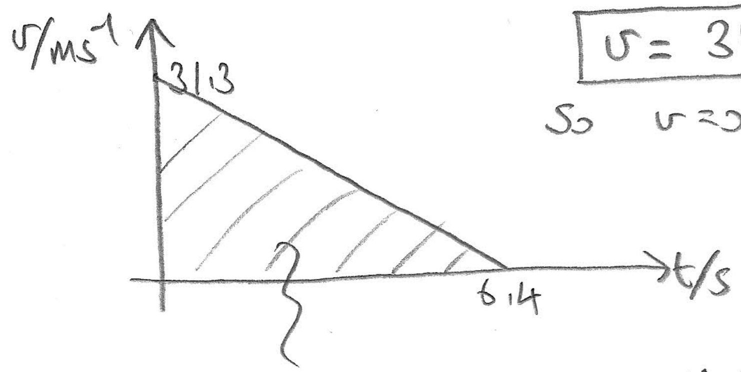
Question 1

(i) What is 70mph in metres per second? (1 mile = 1,609m)

$$70 \text{ mph} = \frac{70 \times 1609\text{m}}{3600\text{s}} = \boxed{31.3 \text{ ms}^{-1}}$$

a

(ii) A car breaks with a uniform acceleration of '0.5g' i.e. about 5ms^{-2}. Draw a *velocity vs time* graph to describe the breaking of a car from 70mph. Hence work out (a) the time it takes to stop and (ii) how far it has travelled since the breaks were applied.



$$\boxed{v = 31.3 - 4.905t}$$

"$v = u - at$"

initial velocity

acceleration

So $v = 0$ when $t = 31.3/4.905$

$= \boxed{6.4\text{s}}$

Area under graph is displacement

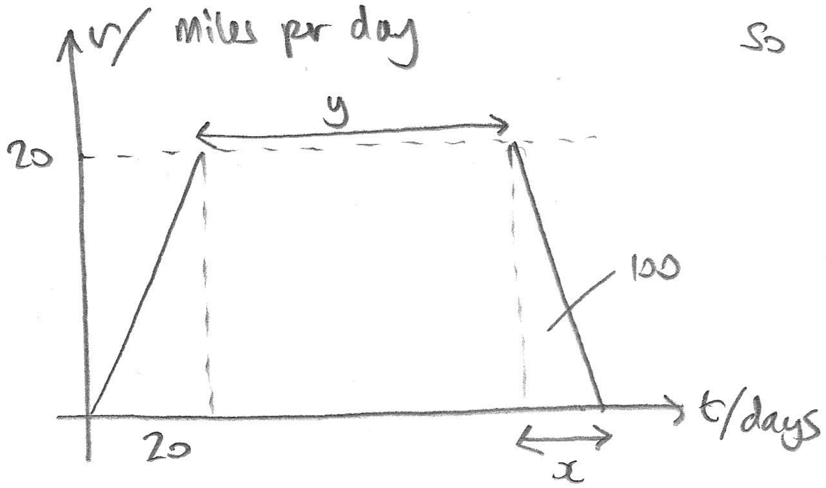
i.e. stopping distance. i.e. $\frac{1}{2}(6.4)(31.3)$

$= \boxed{99.8\text{m}}$

Question 2

Charlie and Craig decide to walk 500 miles, and then 500 more. Excluding any stops, they build up from zero to 20 miles per day over 20 days. They carry on until they have 100 miles left. At this point they slow at a constant rate until they reach their thousand mile target.

Sketch a speed (miles per day) vs time (days) graph, and hence work out how long it takes them.



So $\frac{1}{2} 20x = 100$

$10x = 100$

$\boxed{x = 10 \text{ days}}$

$\frac{1}{2}20(20) + 20y + 100 = 1000$

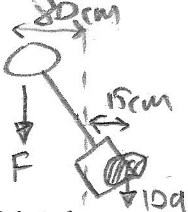
$\therefore 20y = 900 - 200$

$y = \frac{700}{20}$

$y = \boxed{35 \text{ days}}$

So it takes the men $20 + 35 + 10 = \boxed{65 \text{ days}}$

Moments

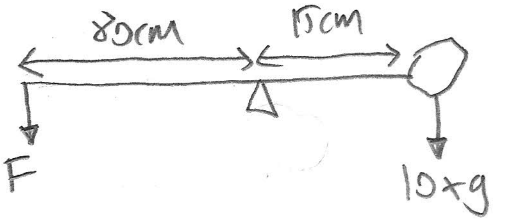


← This is the more realistic diagram.

Question 1

An enormous vegetable (mass 10kg) is to be uprooted with a spade. When the spade is underneath the vegetable, the distance to the pivot point (the top of the spade) is 15cm. A gardener exerts a force at a distance of 80cm from the pivot point. Calculate, in Newtons, what this force needs to be to raise the vegetable. Ignore the weight of soil, and take $g = 9.81\text{ms}^{-2}$.

Essentially we will have this situation:

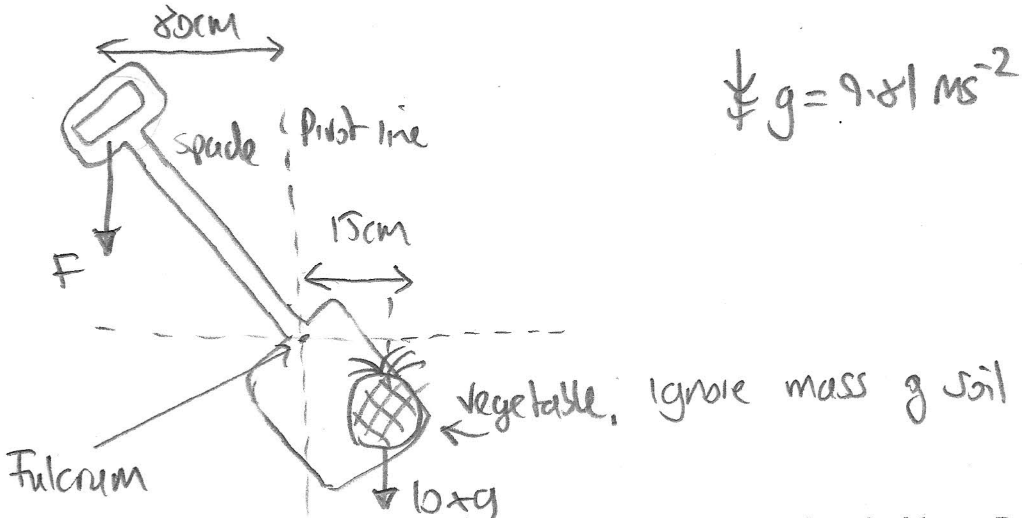


If $F \times 80 > 10 \times g \times 15$ to uproot the vegetable

$$\therefore F > \frac{10 \times 9.81 \times 15}{80}$$

$$\boxed{F > 18.4\text{ N}}$$

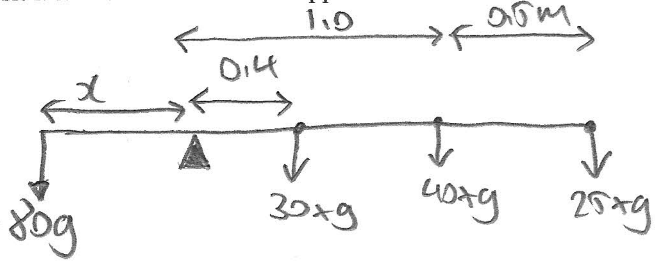
By way of a diagram explain how the distances stated relate to the vegetable, the gardener and the spade.



$g = 9.81\text{ ms}^{-2}$

Question 2

A man takes his three children to the park and they all have a go on a see saw. Anne (30kg) sits 40cm from the fulcrum, Bella (40kg) sits 1m from the fulcrum and Charles (25kg) sits 1.5m from the fulcrum. If the man has a mass of 80kg, calculate how far he must sit from the fulcrum on the opposite side.



$$80x = (0.4)(30) + (1.0)(40) + (1.5)(25)$$

$$\therefore x = \frac{89.5}{80} = \boxed{1.12\text{ m}}$$

Uncle Pete (75kg) now sits 20cm behind his brother, and Auntie Maud sits where Charles sat, and sits him on her lap. How heavy is Auntie Maud?

$$75(1.12 + 0.2) + 80 \times 1.12 = (0.4)(30) + (1.0)(40) + (1.5)(25 + M)$$

$$188.41 - 52 - 37.5 = 1.5M$$

$$\boxed{65.9\text{ kg} = M}$$

Work/Weight/Energy Assume $g = 9.81\text{ms}^{=2}$ unless otherwise stated.

Question 1

Pen-y-Pass Youth Hostel is at an altitude of 359m. The peak of Snowdon is 1,085m. Calculate the work done against gravity if a 72kg man makes the climb. If it takes him two hours, what is the average power expended?

$$E = mgh$$
$$E = 72\times9.81\times(1085-359)$$
$$= \boxed{5.13\times10^5\text{ J}}$$

$$\therefore \text{power is } \frac{5.13\times10^5\text{ J}}{2\times3600\text{ s}}$$
$$= \boxed{71.2\text{ W}}$$

Two oatibix biscuits contain 798kJ of energy. How many ascents of Snowdon correspond to one oatibix?

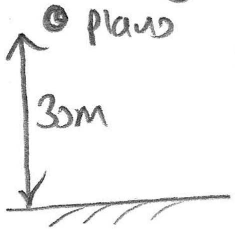
$$\frac{798\times10^3/2}{5.13\times10^5} = \boxed{0.8}$$

So one oatibix is simply not enough!
(and you need to get down too. So eat four :-))

Question 2

A piano falls 30m from a high rise building. Ignoring the effect of air resistance, calculate the velocity of impact.

$$mgh = \frac{1}{2}mv^2$$



$$g = 9.81\text{ms}^{-2}$$

$$\therefore v = \sqrt{2gh}$$
$$v = \sqrt{2\times9.81\times30}$$
$$v = \boxed{24.3\text{ ms}^{-1}}$$

Question 3

Jim the astronaut has a vertical leap of 50cm on Earth. Calculate his launch velocity.

$$mgh = \frac{1}{2}mv^2$$
$$\therefore v = \sqrt{2gh}$$

$$\therefore v = \sqrt{2\times9.81\times0.5} = \boxed{3.13\text{ ms}^{-1}}$$

Assuming a similar launch velocity on the surface of Mars, calculate Jim's leap height. Note $g_{\text{Mars}} = 3.8\text{ms}^{-2}$

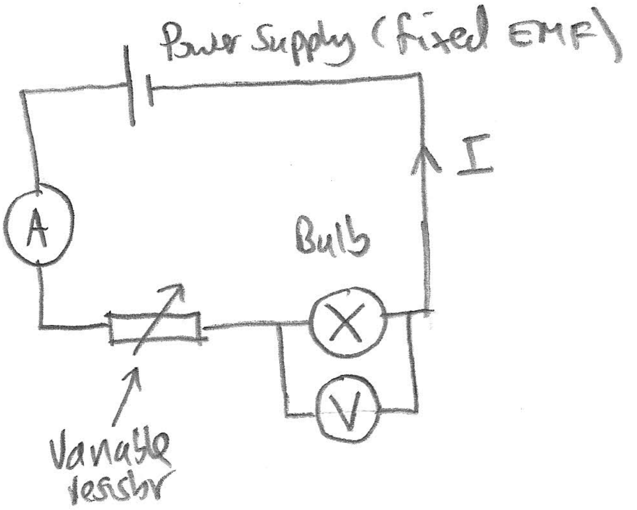
$$\frac{1}{2}mv^2 = mg_{mars}h$$

$$\therefore h = \frac{\frac{1}{2}v^2}{g_{mars}} = \frac{\frac{1}{2}(3.13)^2}{3.8} = \boxed{1.29\text{ m}}$$

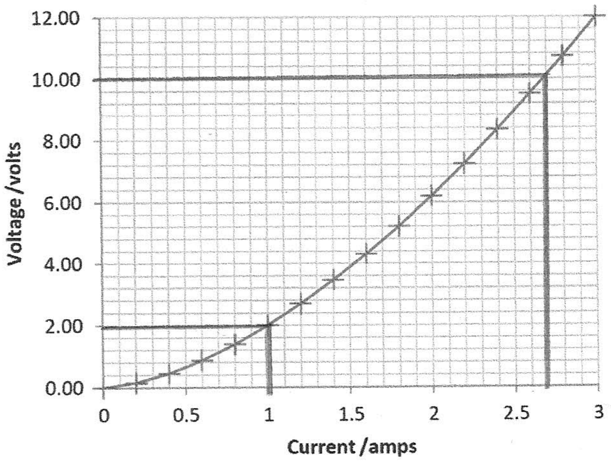
Electricity & Circuits

Question 1

(i) Draw a circuit that could be used to generate the current (I) vs voltage (V) curve below



V vs I curve for a tungsten light-bulb filament



(ii) Use the graph to calculate the resistance at (a) V = 2volts and (b) V = 10volts.

$R = V/I$

a) $V = 2$ volts
$I = 1.0A$
$\therefore \boxed{R = 2.0\Omega}$

b) $V = 10$ volts
$I = 2.7A$
$\therefore \boxed{R = 3.7\Omega}$

(iii) Explain in terms of atoms and electrons, the results in part (ii)

As current I increases, the bulb heats up. This causes the atoms in the filament to vibrate faster, which impedes the motion of electrons. Hence the resistance increases as I does.

Question 2

(a) How much energy is drawn from a 6V battery, if 10 coulombs of charge are transferred? Assume the battery voltage remains constant.

$E = QV \quad \therefore \quad E = 10 \times 6 = \boxed{60J}$

(b) A total of 1000J is extracted from a 12V power supply in 5 minutes. Calculate the average current, in amps.

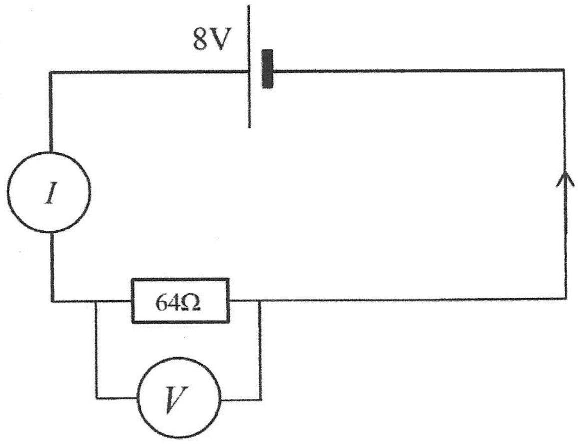
$E = IVt \quad \therefore \quad \frac{E}{Vt} = I \quad \therefore I = \frac{1000J}{12 \times 5 \times 60}$

Power = IV

$I = \boxed{0.28A}$

Question 3

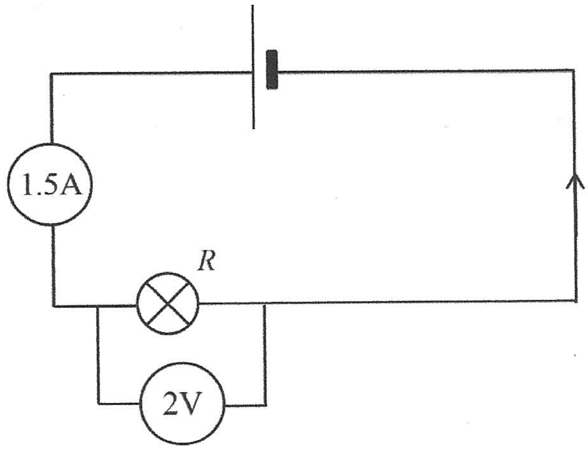
Find the unknown currents, voltages and resistances in each circuit



Assuming wires have negligible resistance

$\boxed{V = 8 \text{ Volts}}$ $\quad I = 8/64 = \frac{1}{8}\,\Omega$

ie $\boxed{I = 0.125A}$

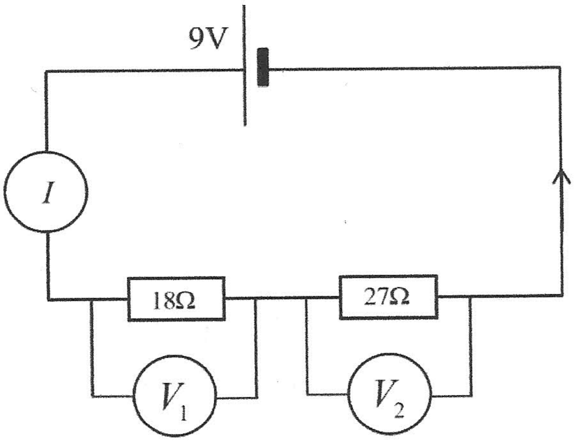


Ohm's Law

("V=IR")

$2 = 1.5R$

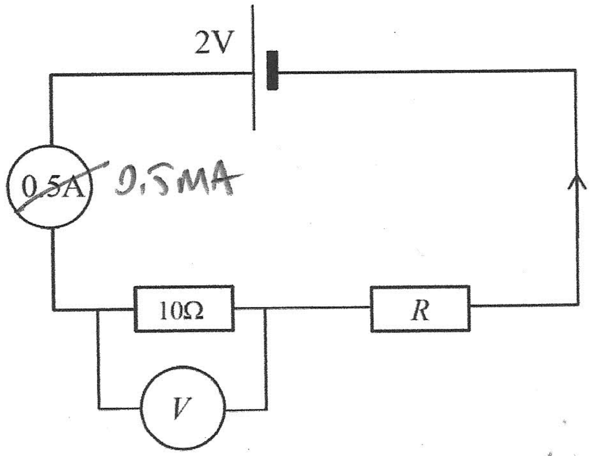
$\therefore \boxed{R = 1.3\,\Omega}$ $\quad (1\tfrac{1}{3}\,\Omega)$



$I = \frac{9}{18+27} = \frac{9}{45} = \boxed{0.2A}$

$\therefore V_1 = \frac{18}{45} \times 9 = 18 \times 0.2 = \boxed{3.6 \text{ Volts}}$

$V_2 = \frac{27}{45} \times 9 = 27 \times 0.2 = \boxed{5.4 \text{ Volts}}$



$2 = 0.5(10 + R) \times 10^{-3}$

$4000 = 10 + R$

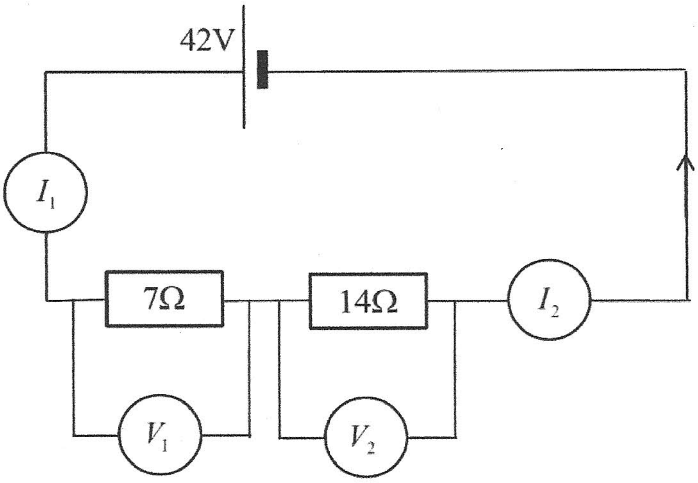
$3990 = R$

$\boxed{R = 3990\,\Omega}$

$V = \frac{10}{10+3990} \times 2 = \boxed{5 \times 10^{-3} \text{ Volts}}$

Question 4

Find the unknown currents, voltages in each circuit



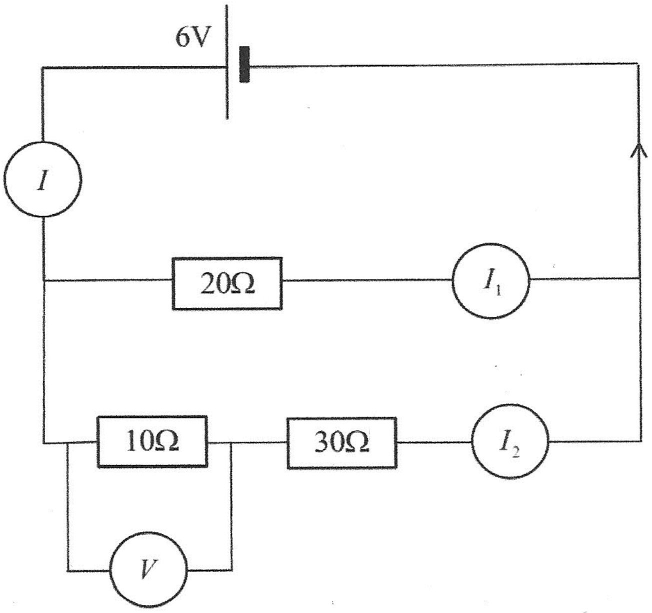
$I_1 = I_2$ since a series loop

$I_1 = \frac{42}{7+14} = \boxed{2A}$

$V_1 = 2\times7 = \boxed{14 \text{ Volts}}$

$V_2 = 2\times14 = \boxed{28 \text{ Volts}}$

check: $14 + 28 = 42$ ✓



$I = I_1 + I_2$

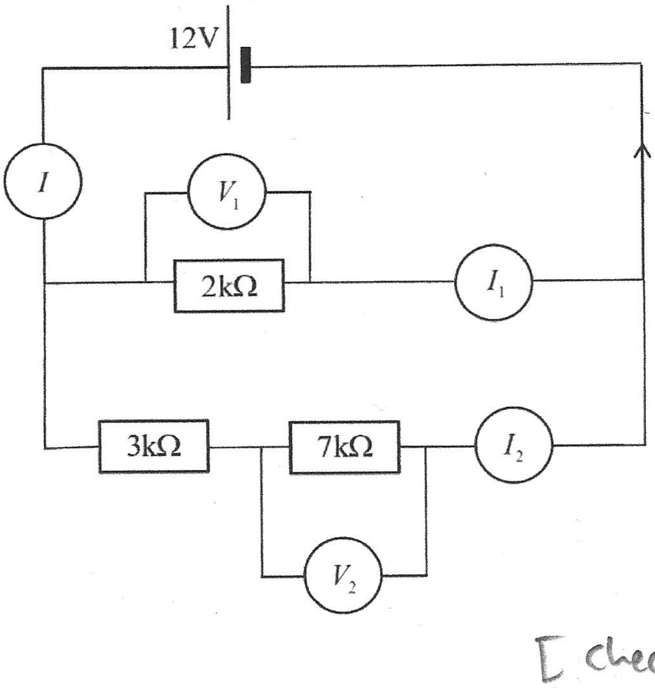
$I_1 = 6/20 = \boxed{0.3A}$

$I_2 = 6/_{10+30} = \boxed{0.15A}$

$\therefore I = \boxed{0.45A}$

$V = I_2 \times 10 = \boxed{1.5 \text{ Volts}}$

$I_1 = {}^{12}/_{2000} = \boxed{6mA}$



$[1 \text{ mA} = 10^{-3} A]$

$I_2 = \frac{12}{(3+7)\times1000} = \boxed{1.2mA}$

$\therefore I = I_1 + I_2 = \boxed{7.2mA}$

$\boxed{V_1 = 12 \text{ Volts}}$

$V_2 = \frac{7}{3+7} \times 12 = \boxed{8.4 \text{ Volts}}$

[check: $V_2 = I_2 \times 7k\Omega = 1.2\times7$
$= 8.4$]

Springs

Question 1

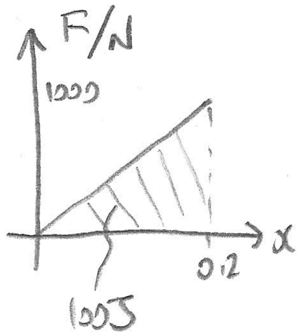
An athlete uses a spring as part of a fitness regime. She expends 100J stretching the spring 20cm. Calculate the spring constant (i.e. the stiffness, in N/m).

$$E = \frac{1}{2} k x^2$$

$$\frac{2E}{x^2} = k$$

$$\therefore k = \frac{2 \times 100}{0.2^2}$$

$$\boxed{k = 5000\ N/m}$$



Hence calculate the maximum force applied to stretch the spring.

$$F_{max} = k \times 0.2$$

$$= \boxed{1000\ N}$$

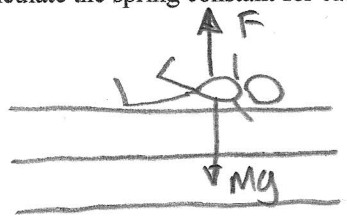
(is equivalent to lifting $\frac{1000}{9.81}$ = 102 kg!)

↑ so perhaps it is not a chest expander!

Question 2

A boy (mass 55kg) piles three pocket-sprung mattresses on top of one another during a boarding house spring clean. He leaps on top and moves downward by 5cm. Assume each mattress is a grid of single identical springs, and 30 springs cover the surface area of the boy on each layer.

Calculate the spring constant for each spring.

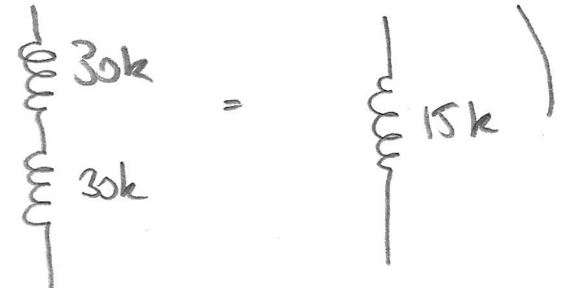


Take $g = 9.81\ ms^{-2}$

If k is the spring constant for each spring

$$F = \frac{30k}{2} x$$

(Equivalent single spring is



)

In equilibrium $F = Mg$

$$\therefore 15k \times 0.05 = 55 \times 9.81$$

$$k = \frac{55 \times 9.81}{15 \times 0.05} = \boxed{719\ N/m}$$

Magnetism

Question 1

Explain why a *soft* magnetic material like iron is often coiled with current carrying wire to make an *electromagnet*, rather than a *hard* magnetic material like steel.

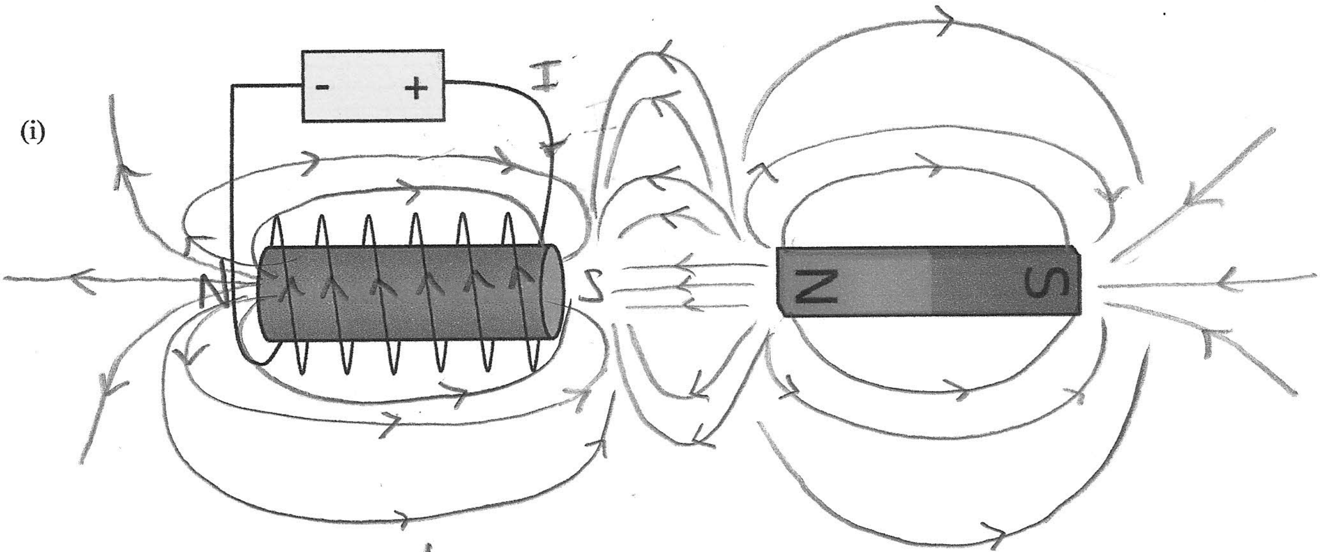
An electromagnet will want to be turned on or off easily, or the polarity of a magnetic field changed rapidly. (eg loudspeaker, transformer etc)

Iron rapidly demagnetizes when the applied field is removed, whereas steel retains the initial magnetism to a much greater extent. Steel is much better as a permanent magnet.

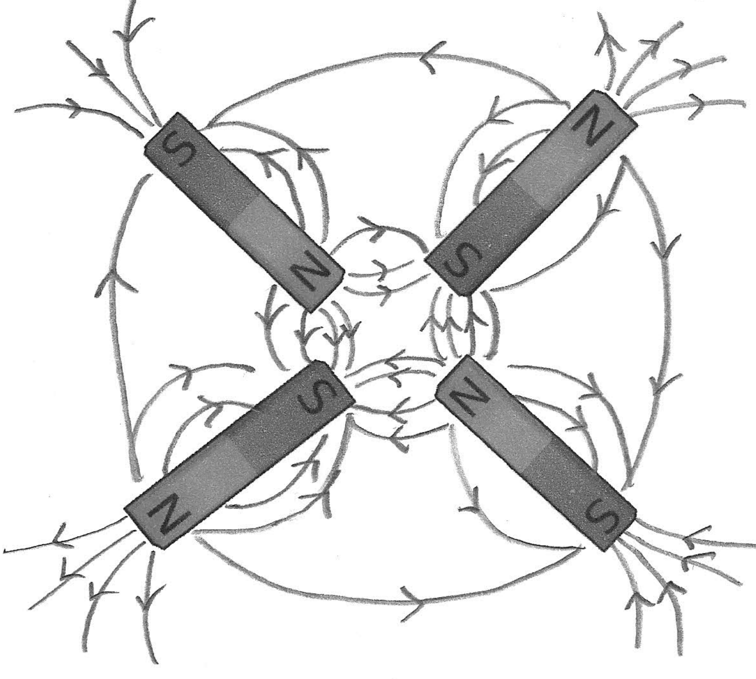
Question 2

Sketch the magnetic field lines around the following magnetic objects

(i)



(ii)



This is called a magnetic quadrupole

It is very useful for focussing beams of charged particles.

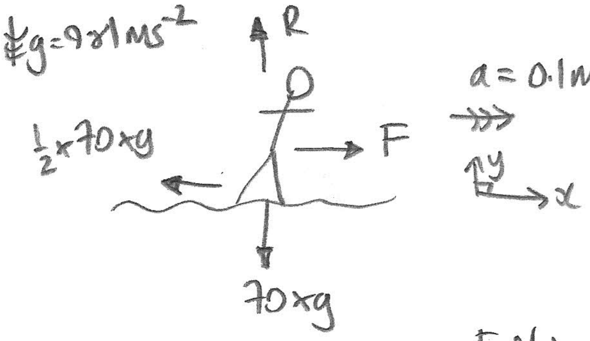
Forces & acceleration

Question 1

A cross-country runner of mass 70kg tries to run through a muddy bog. The resistance of the bog is one half of his weight.

(a) Draw a force diagram to represent the situation, and write down Newton's Second law in terms of quantities you define.

$g = 9.81\,\text{ms}^{-2}$



Newton II:

$/\!/ x: \quad 70a = F - 35\times g$

So $F = 70a + 35\times g$

[Note in y direction, no acceleration so $R = 70\times 9.81$ Normal reaction force with bog.]

(b) Calculate the force the runner must exert in the direction of motion if his acceleration is 0.1ms^{-2}

$a = 0.1\,\text{ms}^{-2}$

$g = 9.81\,\text{ms}^{-2}$

$\therefore F = 70\times 0.1 + 35\times 9.81$

$F = \boxed{350\text{N}}$

(350, 35)

Question 2

Three forces act on a robot dog of mass 11kg.

$$\mathbf{f}_1 = \begin{pmatrix} 2 \\ -3 \end{pmatrix}, \quad \mathbf{f}_2 = \begin{pmatrix} -2 \\ 0 \end{pmatrix}, \quad \mathbf{f}_3 = \begin{pmatrix} -3 \\ -1 \end{pmatrix}$$

$\boxed{\text{Newton II}}$

So $11\underline{a} = \begin{pmatrix} -3 \\ -4 \end{pmatrix}$ $\quad \therefore \underline{a} = \begin{pmatrix} -3/11 \\ -4/11 \end{pmatrix}$ acceleration

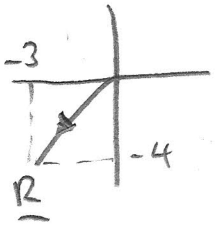
So magnitude of $\boxed{a = 5/11\ \text{ms}^{-2}}$

Find the *resultant* force vector, and hence work out the magnitude of the acceleration of the dog.

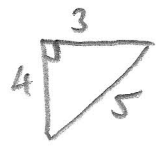
$\underline{R} = \underline{f}_1 + \underline{f}_2 + \underline{f}_3$

$= \begin{pmatrix} 2 \\ -3 \end{pmatrix} + \begin{pmatrix} -2 \\ 0 \end{pmatrix} + \begin{pmatrix} -3 \\ -1 \end{pmatrix}$

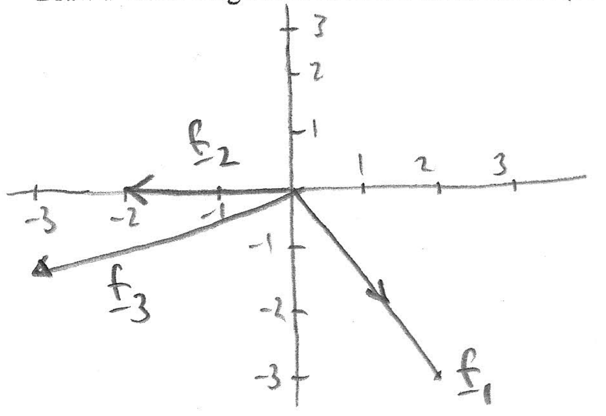
$= \begin{pmatrix} -3 \\ -4 \end{pmatrix}$

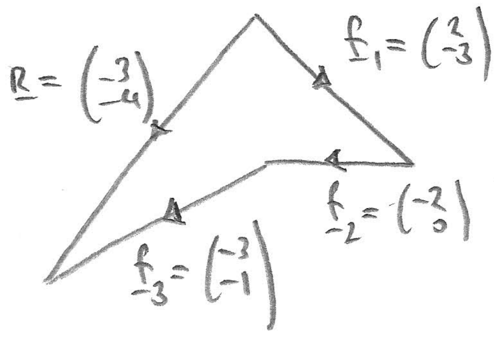


$|\underline{R}| = \boxed{5\text{N}}$



·Draw a vector diagram to show the result above. (Draw a free body diagram, *and* also add the vectors tip to tail).





Light & Sound waves

Question 1

In order to listen to BBC Radio 4, an analogue radio must be tuned to somewhere in between 92MHz and 95MHz.

If the speed of light is $c = 2.998 \times 10^8 \text{ms}^{-1}$, calculate the range of wavelengths (in metres) this corresponds to.

$c = f\lambda \quad \therefore \quad \boxed{\lambda = \frac{c}{f}}$

$\lambda_{min} = \frac{2.998 \times 10^8}{95 \times 10^6} = \boxed{3.16 \text{ m}}$ $\qquad \lambda_{max} = \frac{2.998 \times 10^8}{92 \times 10^6} = \boxed{3.26 \text{ m}}$

Question 2

A laser beam is fired from air into a rectangular block of refractive index $n_1 = 1.4$. The beam continues through the block and then enters another one, with refractive index $n_2 = 1.5$. It then exits this block into air.

Use **Snell's law** to calculate the angles of **refraction** for (i) air to block 1; (ii) block1 to block2 and (iii) block2 to air.

Use this information, and a **pencil, ruler and protractor**, to carefully draw the path of the laser beam using the diagram below.

Don't forget to include reflections as well.

$\boxed{\text{Air to block1:}}$ $1.4 \sin\phi = 1 \times \sin 60°$

$\therefore \phi = \sin^{-1}(\sin 60°/1.4)$

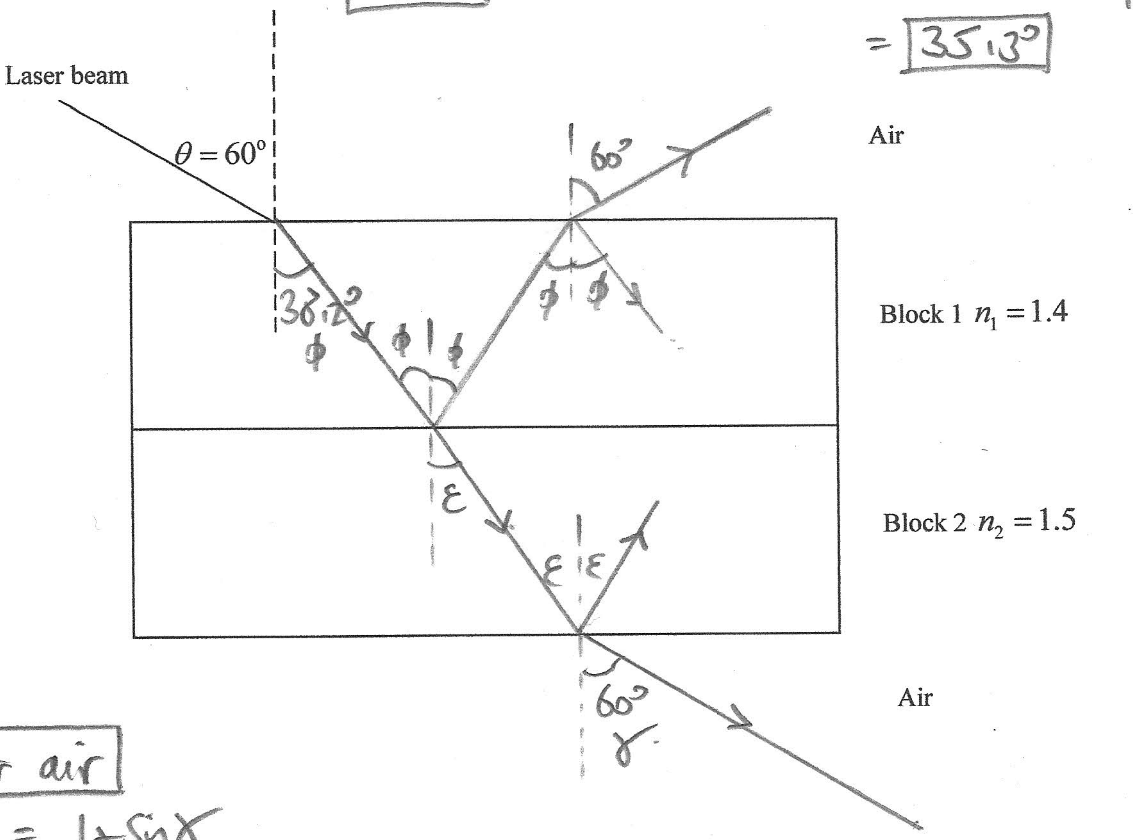
$= \boxed{38.2°}$

$\boxed{\text{Block1 to block2}}$

$1.4 \sin\phi = 1.5 \sin\varepsilon$

$\therefore \varepsilon = \sin^{-1}\left(\frac{1.4 \sin\phi}{1.5}\right)$

$= \boxed{35.3°}$



$\boxed{\text{Block 2 to air}}$

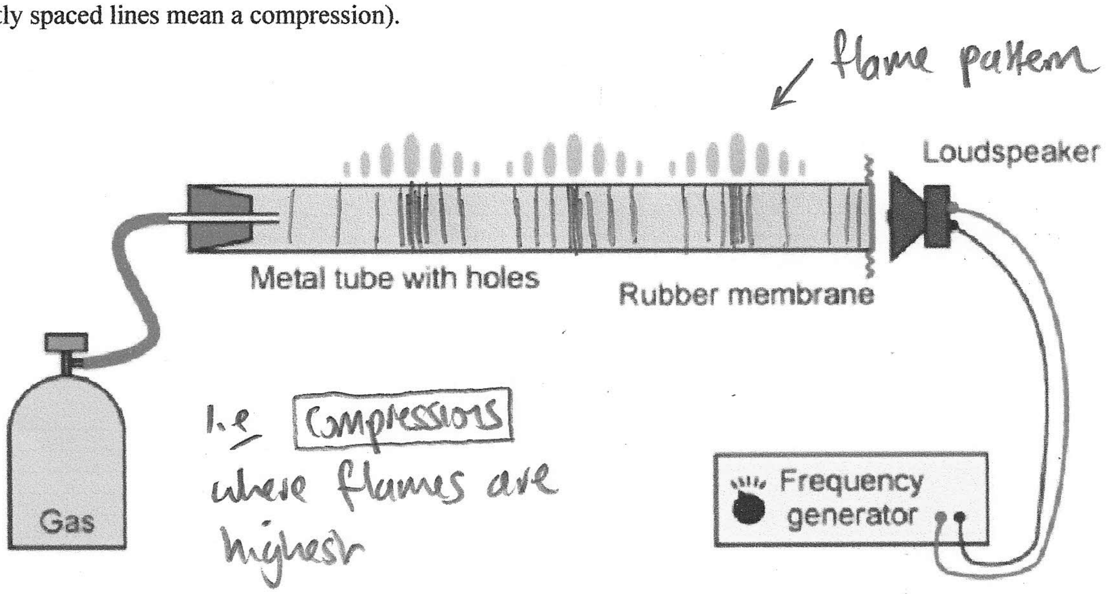
$1.5 \sin\varepsilon = 1 \times \sin\gamma$

$\therefore \gamma = \sin^{-1}(1.5 \sin\varepsilon) = \boxed{60°}$

So emerging ray is // to incident ray

Question 3

A Rubens Tube is described below. Use vertical lines to indicate the positions of compressions and rarefactions of the gas in the tube. (Tightly spaced lines mean a compression).

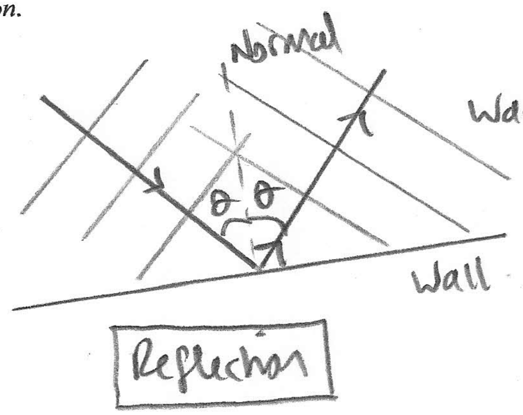


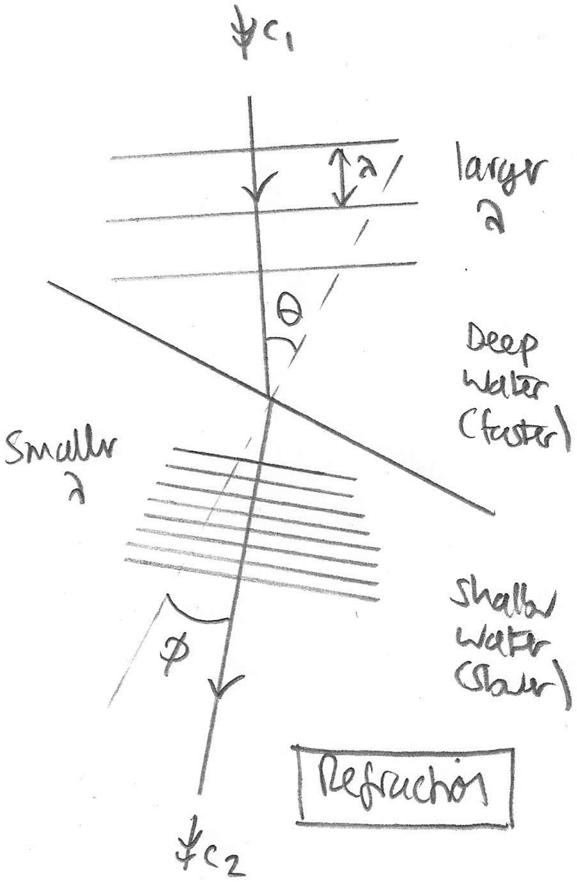
i.e $\boxed{\text{Compressions}}$ where flames are highest

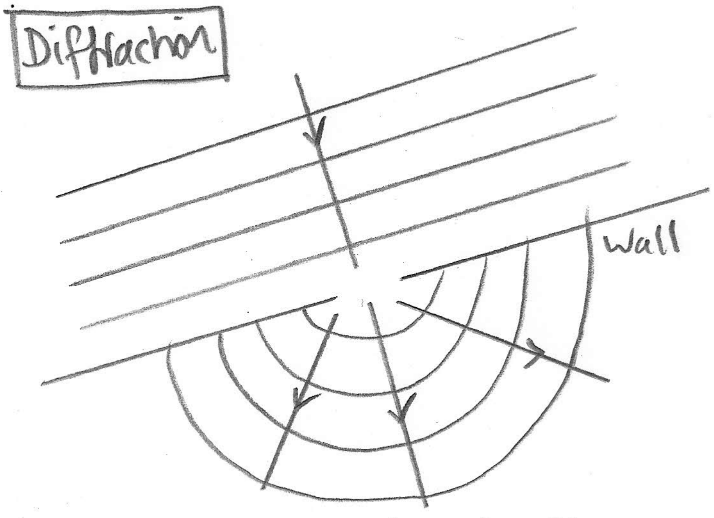
$\boxed{\text{Rarefactions}}$ at nodes ← i.e. "zeros" of flame pattern.

Question 4

Using water waves as an example, draw three sketches (with wave-front lines, and arrows) to represent *reflection*, *refraction* and *diffraction*.







(Assume same depth either side of wall)

$$\boxed{\frac{1}{c_1}\sin\theta = \frac{1}{c_2}\sin\phi \quad \text{Snell's Law}}$$

Note in all case $c_1 > c_2 \Rightarrow \theta > \phi$

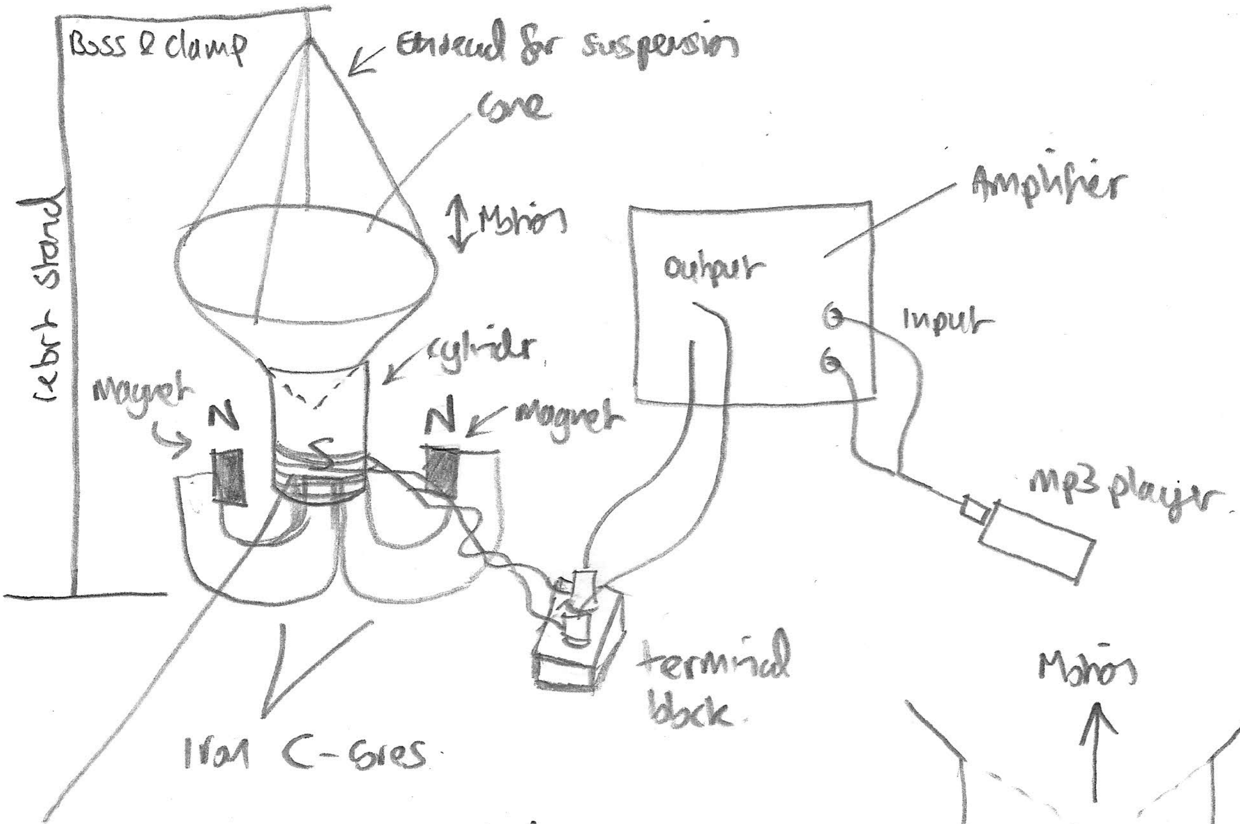
Power & electromagnetism

Question 1

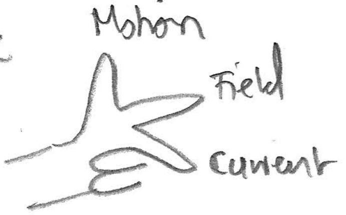
Using appropriate diagrams, explain how to make a **loudspeaker** out of card, wire, sticky tape, magnets and an amplified signal from an mp3 player.

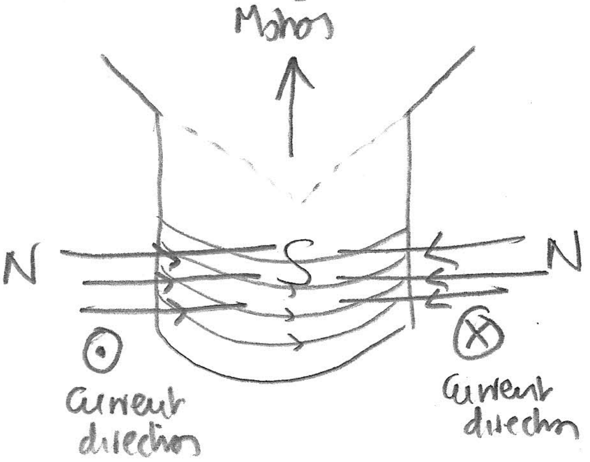
Explain using ideas of **electromagnetism**, *why* the speaker cone can be made to move in time with the electrical signal.

Explain briefly how the design could be modified to generate louder sounds, *without* changing the current in the wires.



About 2.2 m of wire coiled around cylinder



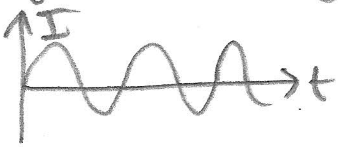


Fleming's left hand rule

describes the Lorentz force on a current carrying wire in a magnetic field.

Since the field is fixed, motion occurs 'in time' with changes in the current in the wire. An analogue sound signal will vary 'up and down' and ∴ so will the cone.

eg



The cone pushes against the air and ∴ produces sound.

For louder sounds...
- magnets all round the cylinder
- More wire coils / cm
- Stronger magnets
- larger cone
- Stiffer cone material