Yr 12 ATAR Physics –Electric and Magnetic Fields Test

NAME: ______________________________

Total Marks – 46

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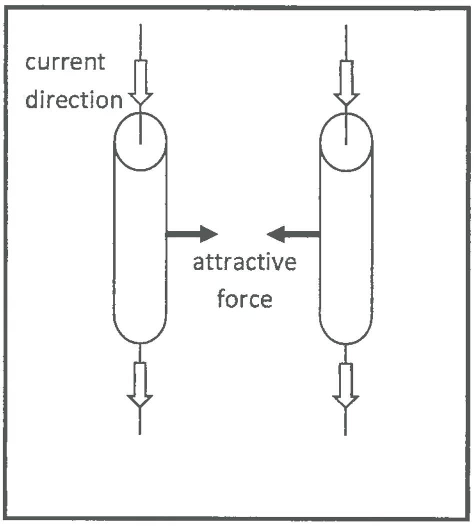
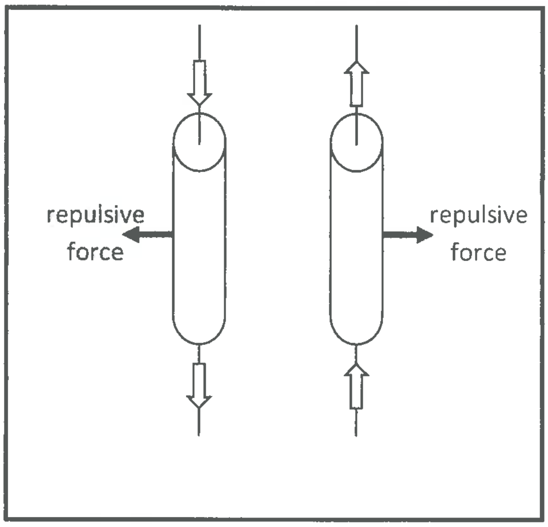
1. The Laws of Magnetism state that *"unlike poles (fields) attract, while like poles (fields) repel."*

a). Discuss these laws with relation to two parallel conductors, each carrying an electric current and the fact that when the currents flow in similar directions, the conductors appear to experience an attractive force, and vice versa as shown below. Include diagrams in your explanation (space for diagrams is included below).

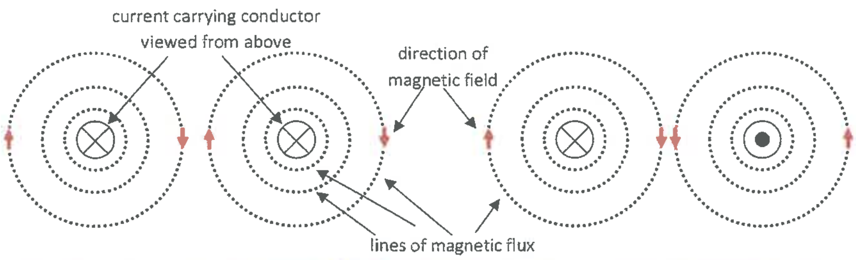
(4 Marks)



currents flowing in <u>same</u> direction



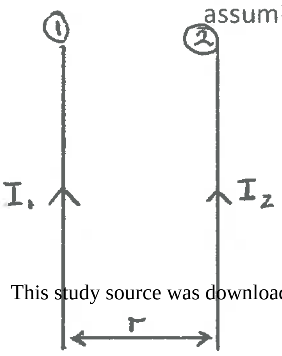
currents flowing in <u>opposite</u> directions



It is the relative direction of the **magnetic fields** and not the direction of current flow which dictates whether the force will be attractive or repulsive. When the currents flow in the same direction, the respective magnetic fields between the conductors are actually opposing each other, therefore fields are unlike and so the force is attractive. The reverse is true when the currents flow in opposite directions, as shown above.

b). Derive an expression which will allow the force between two infinitely long parallel wires (positioned a distance 'r' apart, carrying currents I_1 and I_2 respectively) to be calculated, assuming that they are separated by air.

(2 Marks)



wire① exerts a force on wire② given by:

$F = B_1 I_2 L$ where B_1 = magnetic field created by wire①,

since $B_1 = \frac{\mu_0 I_1}{2\pi r}$, then $F = \frac{\mu_0 I_1 I_2 L}{2\pi r}$

therefore $\frac{F}{L} = \frac{\mu_0 I_1 I_2}{2\pi r}$

c). Use this expression to calculate the force between two such wires, each 80 cm long, carrying currents of 400 mA and 500 mA respectively if they are 40 cm apart.

(3 Marks)

If you could not answer part b)., then use the fact that the force acting per unit length between two parallel wires is given by:

$$\frac{F}{L} = \frac{\mu_0 I_1 I_2}{2\Pi r}$$

$I_1 = 0{\cdot}4\,A$
$I_2 = 0{\cdot}5\,A$
$\mu_0 = 4\pi \times 10^{-7}\,Hm^{-1}$
$r = 0{\cdot}\cancel{8}4\,m$
$L = 0{\cdot}8\,m$

$$F = \frac{\mu_0 I_1 I_2 L}{2\pi r}$$

$$\therefore F = \frac{{}^{2}\cancel{4\pi} \times 10^{-7} \times \cancel{0{\cdot}4} \times 0{\cdot}5 \times 0{\cdot}8}{\cancel{2\pi} \times \cancel{0{\cdot}4}} = 8{\cdot}0 \times 10^{-8}\,N.$$

- could either be attractive or repulsive, depending on relative current directions.

2. The distance separating the proton and the electron in an atom of Hydrogen is 1.0 x 10^{-10}m. Use Coulomb's Law to calculate the attractive force which exists between these subatomic particles.

(3 Marks)

$F = \dfrac{q_1 q_2}{4\pi\varepsilon_0 r^2}$; $q_p = 1{\cdot}6 \times 10^{-19}\,C$, $q_e = 1{\cdot}6 \times 10^{-19}\,C$,

$\varepsilon_0 = 8{\cdot}85 \times 10^{-12}\,Fm^{-1}$, $r = 1{\cdot}0 \times 10^{-10}\,m$

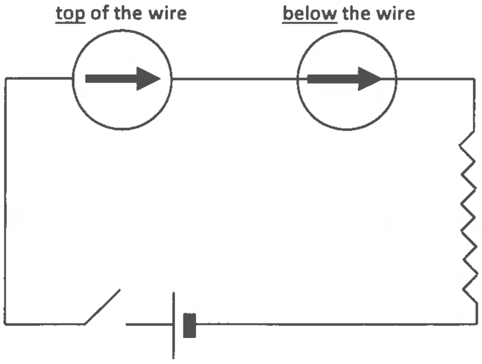
$$F = \frac{(1{\cdot}6 \times 10^{-19})^2}{4\pi \times 8{\cdot}85 \times 10^{-12} \times (1 \times 10^{-10})^2} = 2{\cdot}30 \times 10^{-8}\,N$$

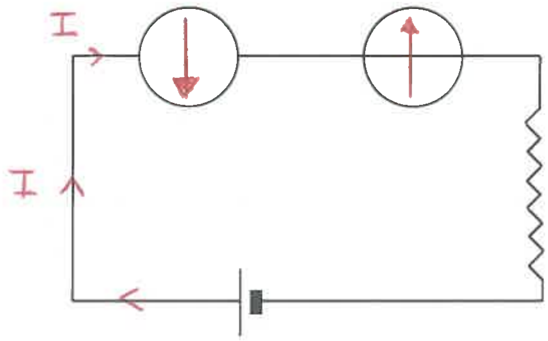
3. In the following diagrams, a circuit has two compasses placed near the wire of a circuit. One compass is **on top** of the wire and one is **underneath** the wire. When the switch is open the wire is in line with the compass needles. When the switch is closed, draw the position of the compass needles [hint: apply the 'right hand grip rule to the wire carrying the current!].

(1 Mark)

this compass is on top of the wire

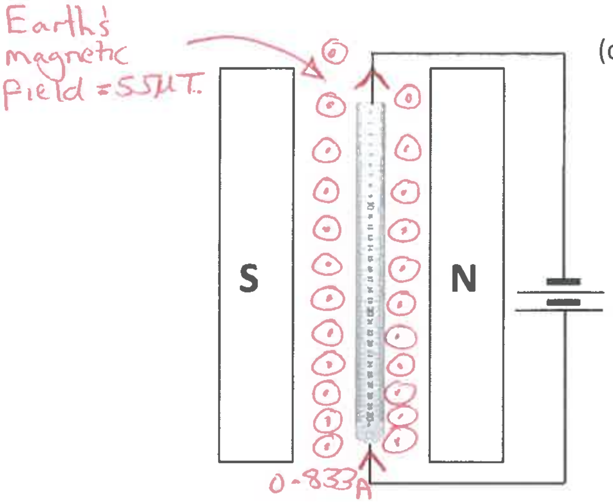
this compass is below the wire





- using the Right Hand Grip rule gives the direction of the circular magnetic field around the relevant section of wire.

4. A 30 cm metal ruler of resistance 1.8 Ω is attached to a 1.5 V battery in an Australian school's Physics laboratory and held between the poles of a permanent magnet, which provides a **horizontal** B-field of magnitude 80 μT. It is also subjected to the Earth's magnetic field (55 μT), which can be assumed to be **vertical** to the table on which the ruler rests. Calculate the size **and** direction of the **resultant force** acting on the ruler **and** suggest why the ruler does not move under the influence of this force. **(6 Marks)**



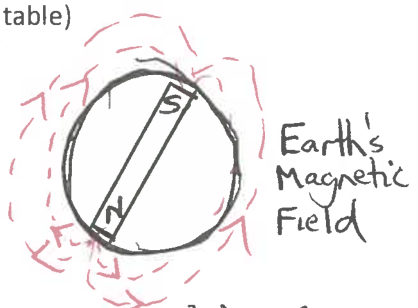
(diagram viewed from above the table)

$I = \frac{V}{R}$

$= \frac{1.5}{1.8}$

$= 0.833A$

as shown on diagram!



so, in Australia, the Earth's magnetic field would appear to travel vertically upwards out of the ground, as indicated on the diagram!

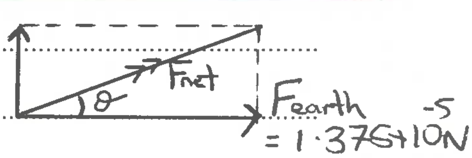
force on ruler due to Earth's mag. field, $F = BIL$

$\therefore F_{earth} = 55 \times 10^{-6} \times 0.833 \times 0.3 = 1.375 \times 10^{-5}$ N to the RIGHT

force on ruler due to applied magnet's field, $F = BIL$

$\therefore F_{magnet} = 80 \times 10^{-6} \times 0.833 \times 0.3 = 2.00 \times 10^{-5}$ N out of the page

view ruler horizontally from its 30 cm end:

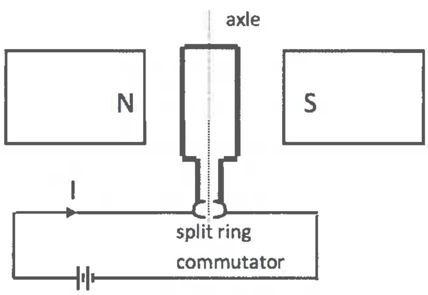


Resultant force on ruler, $F_{net} = \sqrt{(2.0 \times 10^{-5})^2 + (1.375 \times 10^{-5})^2} = 2.43 \times 10^{-5}$ N

at angle, $\theta = \tan^{-1}\left(\frac{2.0 \times 10^{-5}}{1.375 \times 10^{-5}}\right) = \tan^{-1}(1.455) = 55.5^{\circ}$

Friction between the ruler and table top would be much greater than this value!

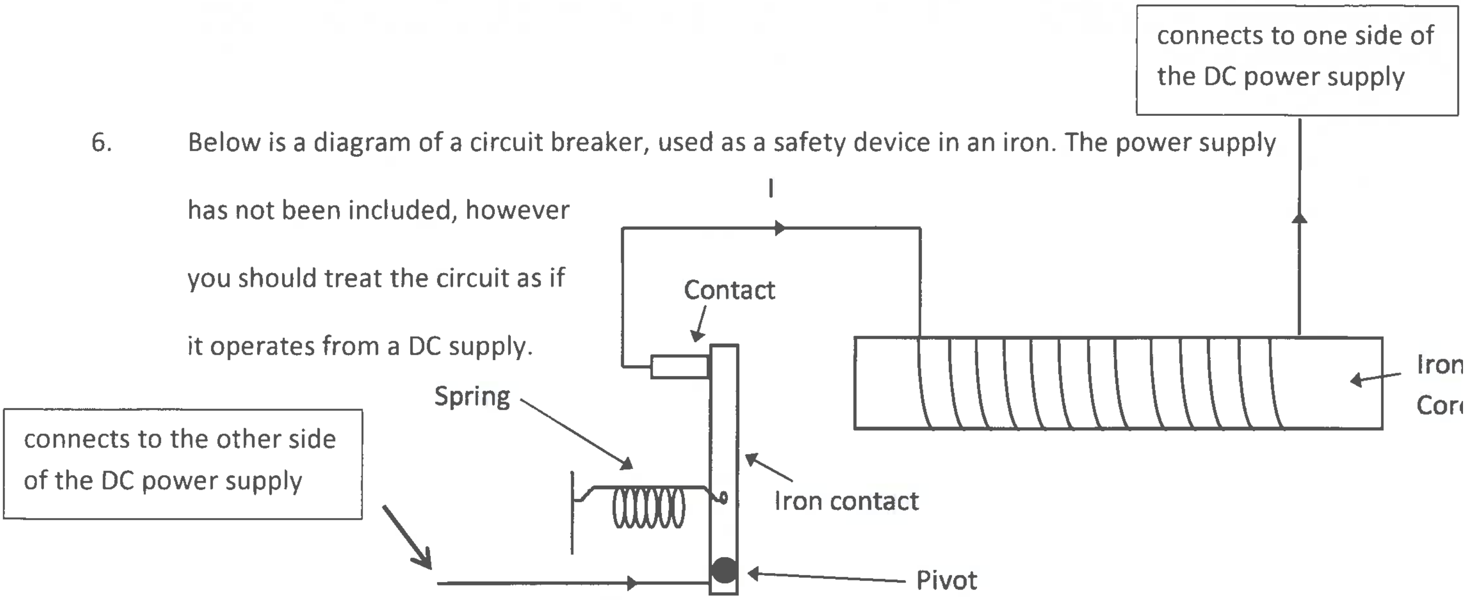
5. A DC motor has a current flowing through a rectangular armature as shown below.



What will be the direction of rotation when the current is switched on, as viewed from the end with the split ring commutator – CLOCKWISE or ANTICLOCKWISE (circle your answer)?

(1 Mark)

6. Below is a diagram of a circuit breaker, used as a safety device in an iron. The power supply has not been included, however you should treat the circuit as if it operates from a DC supply.



a). Describe how the circuit breaker operates;

i). under normal conditions (i.e. the iron operates safely using its required current(**(2 Marks)**

- when working normally, the magnetic field produced by the working current is NOT strong enough to attract the iron contact (spring is too stiff!) so circuit remains intact and complete.

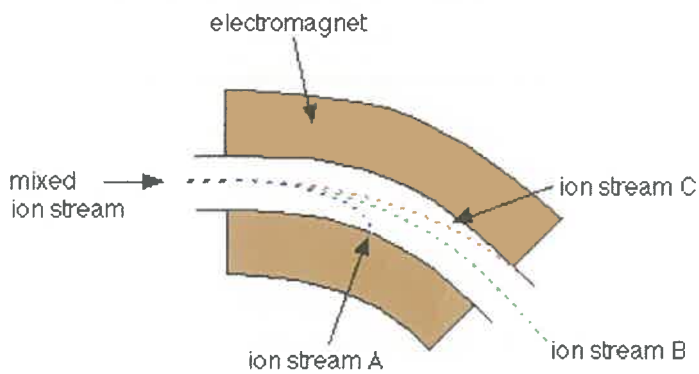
ii). when an excessive current flows through the circuit. **(2 Marks)**

- a larger current produces a stronger magnetic field which will attract the iron contact towards the iron core. This will in turn cause a gap in the circuit and the current will stop flowing.

b). What can the manufacturers do to **increase** the current rating of the circuit breaker (i.e. the current that will break the circuit and automatically turn off the iron)? **(3 Marks)**

- in order to INCREASE the current required to turn off the iron:
  - REDUCE the number of turns on the iron core
  - INCREASE the distance between iron core and iron contact
  - use a STIFFER spring
  - REDUCE the size of the iron core

7. The diagram below shows the part of a mass spectrometer where a stream of charged particles is deflected by a uniform magnetic field. The ion beam consists of **positive particles** that are **singly charged** (ie: have a charge of + 1.6×10^{-19} C). The intensity of the magnetic field is 1.21 T and all particles have a speed of 1.0×10^{6} m s^{-1}.



i). State the direction of the magnetic field of the electromagnet. **(1 Mark)**

INTO THE PAGE or **OUT OF THE PAGE** (circle the correct answer)

ii). Which ion stream, A, B or C consists of ions of the greatest mass? Explain. **(2 Marks)**

Stream A or **Stream B** or **Stream C** (circle the correct answer)

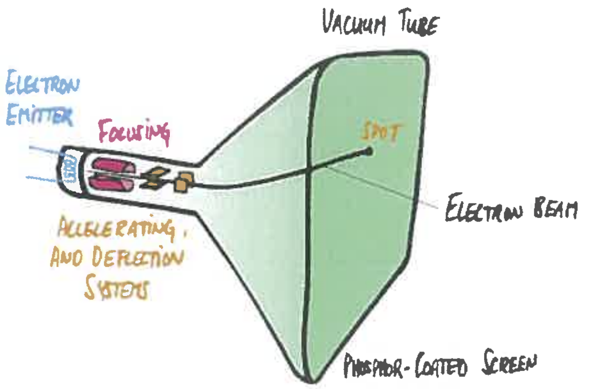
since $r = mV/Bq$, then for constant V, B and q, as 'm' increases, so does radius, r ∴ heaviest particles = biggest radius.

iii). If the ion stream B has a radius of curvature of 38.0 cm, find the mass of one of its particles. **(2 Marks)**

$r = 0.38\,m$; $m = \dfrac{Bqr}{V} = \dfrac{1.21 \times 1.6\times10^{-19} \times 0.38}{1.0\times10^{6}}$

$\therefore m = 7.36\times10^{-26}$ kg

iv). A television tube consists of a beam of electrons striking a phosphorescence screen. How could you prove that the beam consists of electrons and not protons? **(2 Marks)**

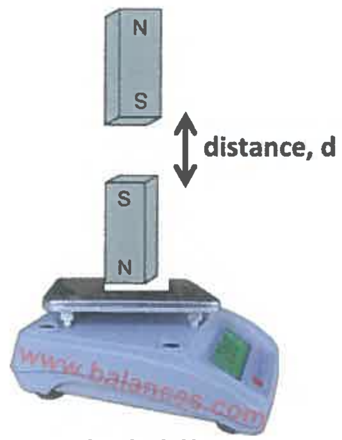


- apply either a magnetic field or an electric field across the beam of electrons
- depending on the direction of the applied field, the electrons would move in the opposite direction to protons.

8. It is said that the intensity of the magnetic field produced by any source of magnetism decreases according to the Inverse Square Law, in a similar way to gravitational fields.

$$B \propto \frac{1}{d^2}$$

This relationship can be investigated and verified by standing a bar magnet on top of an electronic balance as shown below and then holding a second bar magnet in a fixed position at a distance **d** above it (opposing poles facing each other).



After positioning the first magnet on top of the balance, the digital reading was 'zeroed' in order that the mass of the magnet can be ignored from further readings and the scale set to record additional weight (in Newtons) rather than mass (in grams). As the second magnet was brought closer and closer to the first magnet (i.e. the distance 'd' was decreased), the reading was seen to increase, suggesting that this magnet was effectively getting heavier. Of course, it was simply being repelled by the upper magnet due to the presence of a magnetic force. No additional weight was recorded until the magnets were about 40 cm apart.

As the readings were recognising additional weight on the balance, they were effectively measuring the magnetic force being applied on the lower magnet due to the approaching upper magnet. It is then reasonable to assume that this magnetic force is proportional to the magnetic field strength (i.e. the B-field) being applied by the upper magnet on its resting counterpart.

A student collected the data below, using a metre rule having an uncertainty of ±5 mm.

Distance, d (m)	d^2 (m^2)	$1/d^2$ (m^{-2})	Balance reading (N)
0.400 ± 0.005	0.160 ± 0.010	6.25 ± 0.40	2.50
0.350 ± 0.005	0.123 ± 0.010	8.13 ± 0.40	3.34
0.300 ± 0.005	0.090 ± 0.010	11.11 ± 0.40	4.35
0.250 ± 0.005	0.063 ± 0.010	16.00 ± 0.40	6.50
0.200 ± 0.005	0.040 ± 0.010	25.00 ± 0.40	10.00
0.150 ± 0.005	0.023 ± 0.010	44.44 ± 0.40	17.80
0.100 ± 0.005	the lower magnet toppled over and fell off the balance		

NB: since the measured distances, 'd' are **ALL** accurate to within 0.005 m, then the subsequent calculations of **ALL** 'd^2' values will be accurate to double this value (± 0.010 m^2), as indicated by the first two rows of the table which have **almost** been completed for you. Assume that the follow thorough uncertainty with **ALL** '$1/d^2$' values is ± 0.40 m^{-2} as suggested in the table.

a). Complete the table by calculating the missing '**d^2**' and '**$1/d^2$**' values. **(2 Marks)**

b). Use the above data and the grid opposite to plot a relevant graph in order to verify an Inverse Square Law relationship between B-field and distance (**include error bars on your graph**).

eg. the first value for $1/d^2$ is 6.25 ± 0.40 m^{-2} – this means it could have any value between 5.85 m^{-2} and 6.65 m^{-2} **(5 Marks)**

c). Does the graph indeed suggest that the magnetic force and therefore the magnetic field strength (B) created by the bar magnet follows an Inverse Square Law relationship with distance from the magnet? Explain your reasoning. **(2 Marks)**

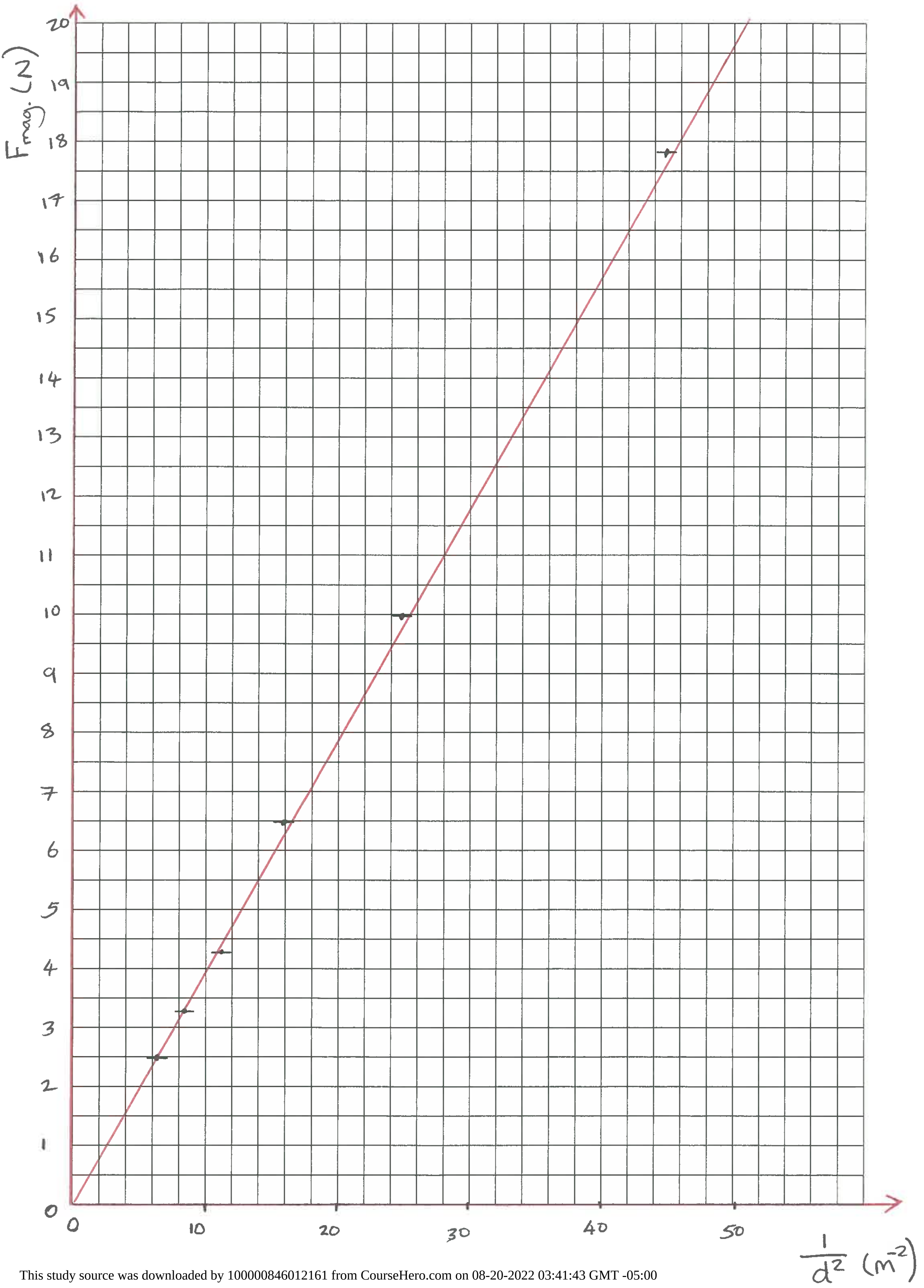
- the graph suggests a strong directly proportional relationship between the magnetic force and $1/d^2$

- since $B \propto F$, then $B \propto 1/d^2$, so YES, the inverse square law is reinforced.

d). Why do you think that the magnet resting on the balance fell over when the second magnet got to within 10 cm of it? Use your graph to predict what the magnetic force acting on this magnet would have been at this distance. **(3 Marks)**

- for $d = 0.10$ m, $1/d^2 = 100\ m^{-2}$
- from graph, F_{mag} at $50\ m^{-2}$ = 19.5 N so it would be TWICE this value at $100\ m^{-2}$ $\therefore$ F at 10 cm $\approx$ 39N ± 1 N.
- this force is too great for the lower magnet which tips over.

* could also answer this question by finding and using the gradient of the graph (which is about 0.39 Nm^2)


F_mag. (N)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
0
10
20
30
40
50
1/d² (m⁻²)