(19 marks)

A student performed an experiment to investigate how the magnetic field strength of a bar magnet varied with distance from the magnet along a line through the long axis of the magnet. She measured the angle θ between the pointer of a plotting compass and geographic north, as she moved the plotting compass to various distances (d) away from the magnet. She measured the angle θ at intervals of 3.0 cm, as shown in Diagram A.

Diagram A

Magnet   Plotting
                  compass

Earth's magnetic
field direction
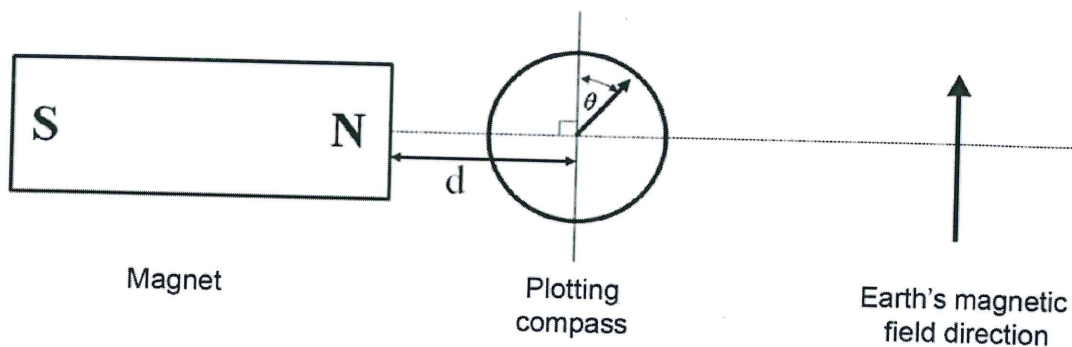
(a) On Diagram B, draw arrows on each of the plotting compasses to indicate the angle you would expect the needle of the compass to make when it is close to, and when it is far (more than 50 cm) from, the bar magnet.

(2 marks)

Magnet   Plotting compass (close)

Plotting compass (far)
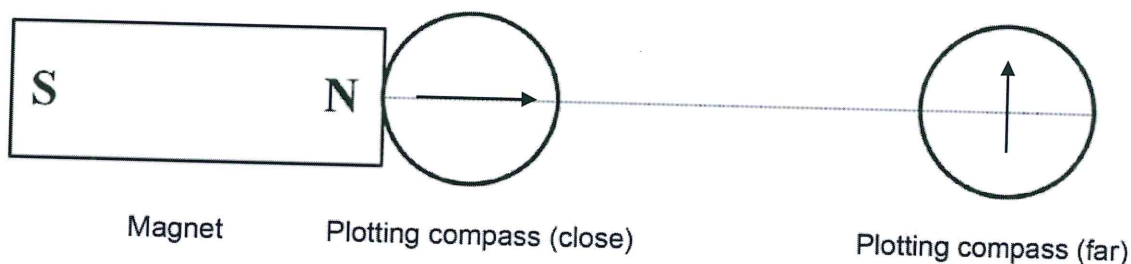
Description	Marks
Arrow is very close to horizontal ⟶	1
Arrow is closely aligned to north ↑	1
	Total 2

(b) Both the Earth's magnetic field and the bar magnet's magnetic field affect the compass. Draw a vector diagram that shows these two magnetic fields and the resultant magnetic field experienced by the plotting compass shown in Diagram A. Use your diagram to derive a relationship between the Earth's magnetic field, the magnet's magnetic field and the angle θ.
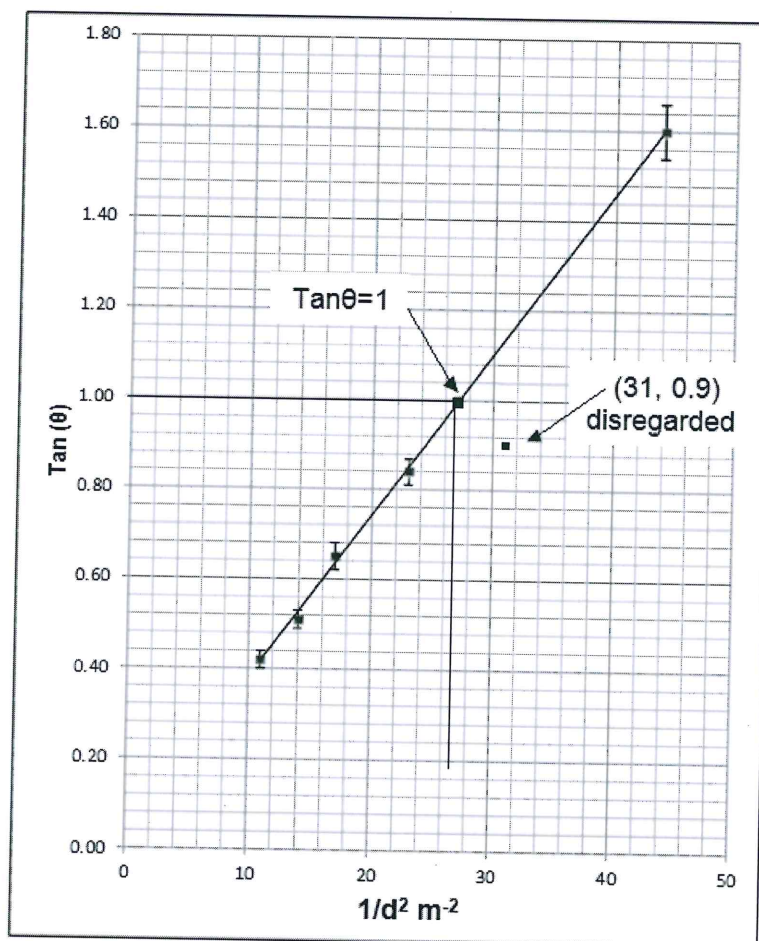
(3 marks)

Description	Marks
Diagram has B fields at right angles θ correctly indicated (arrows in correct directions)	1–2
$\tan \theta = \dfrac{B_{magnet}}{B_{Earth}}$	1
	Total 3

(e)   Plot the graph of tan θ versus $\frac{1}{d^2}$ on the following graph paper. Include error bars and a line of best fit.

(5 marks)

Description	Marks
Axes labelled correctly with units	1
Data points correct	1
Error bars included	1
Line of best fit drawn	1
Outlier left out of line of best fit (tan1→27) (tan1→28+ with outlier included)	1
	Total 5

(f)   Mark and label the point on your graph where the strength of the Earth's magnetic field is equal to the strength of the magnetic field of the bar magnet. Use this point to determine the distance from the magnet where these fields are equal.   (4 marks)

Description	Marks
When B_{earth} = B_{magnet} tan θ = 1	1
Point indicated and labeled	1
from graph this occurs at when $1/d^2$ = 27 m^{-2}	1
d = 19 cm	1
	Total 4

(c) Calculate the strength of the magnetic field due to the bar magnet at a point on the axis, 10.0 cm from the end of the bar magnet, if the value of θ at this point is 82°, and the Earth's magnetic field strength is 2.0×10^{-5} T.

(2 marks)

Description	Marks
$B_{magnet} = B_E \times \tan\theta = 2.0 \times 10^{-5} \times \tan(82°)$	1
$B_{magnet} = 1.4 \times 10^{-4}$ T	1
	Total 2

Parts (d), (e) and (f) of this question assess your understanding of uncertainty in measurements, interpretation of graphs and use of appropriate significant figures.

The compass that the student used to measure the angle θ was marked in divisions of 1°. The student could see when the needle was between divisions but could not judge accurately how close to a division it was. The student decided to express all her measurements of θ with an uncertainty of ± 1°. The student was confident that she placed the centre of the compass on the ruler accurately so decided not to express her measurements of d with any uncertainty. The student's results are shown in the table below.

Distance from magnet (m)	$\dfrac{1}{d^2}$ (m^{-2})	θ (°)	Tan θ
0.15	44	58 ± 1	1.60 ± 0.06
0.18	31	42 ± 1	0.90 ± 0.03
0.21	23	40 ± 1	0.84 ± 0.03
0.24	17	33 ± 1	0.65 ± 0.02
0.27	14	27 ± 1	0.51 ± 0.02
0.30	11	23 ± 1	0.42 ± 0.02

(d) Complete the table by filling in the values for $\dfrac{1}{d^2}$ and the uncertainty range for the value of tan θ for θ = 58°. You must show your calculation for determining the uncertainty range.

(3 marks)

Description	Marks
Correctly complete table for $\dfrac{1}{d^2}$ to 2 sig figs	1
58.0° ± 1 = is 57° to 59°; tan 57° = 1.54 to tan 59° = 1.66	1
(1.66-1.54)/2 = ± 0.06	1
	Total 3