

# GRAVITATION

Challenging **MCQ** questions by The Physics Cafe

**Compiled and selected by The Physics Cafe**



1

The curve in Fig.3.1 shows the way in which the gravitational potential energy of a body of mass  $m$  in the field of the Earth depends on  $r$ , the distance from the centre of the Earth, for values of  $r$  greater than the Earth's radius  $R_E$ .

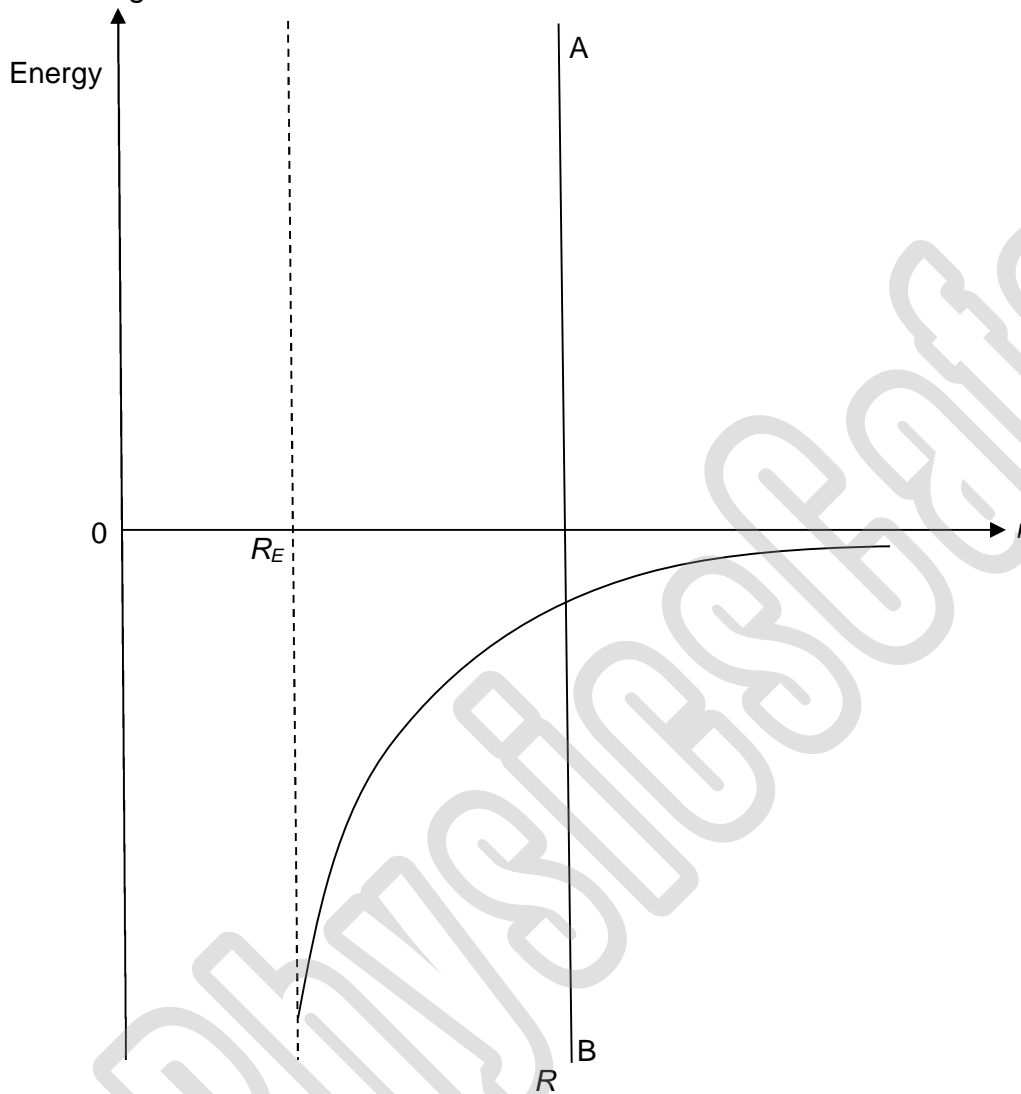


Fig.3.1

The body referred in Fig. 3.1 is a rock which is projected vertically upwards from the Earth. Assume air resistance can be neglected.

At a certain distance  $R$  from the centre of the Earth, the total energy of the rock (i.e. its gravitational potential energy plus its kinetic energy) may be represented by a point on the line AB.

(a) For a rock that is momentarily at rest at the top of its trajectory, which is at the distance  $R$  from the centre of the Earth,

(i) mark its total energy on the line AB in Fig.3.1 with a cross and label it P.

[1]

(ii) sketch the variation of its kinetic energy with distance from the centre of the Earth on Fig.3.1.

[2]

**(b)** The escape speed of the rock is the minimum speed that the rock must possess when it is on the Earth's surface so that it can escape to infinity.

**(i)** On Fig.3.1, mark on the line AB with a cross and label it Q to represent the total energy of the rock if it were projected from the Earth with the escape speed.

[1]

**(ii)** Explain why the minimum speed for the rock to reach the moon from the surface of the Earth is less than the escape speed.

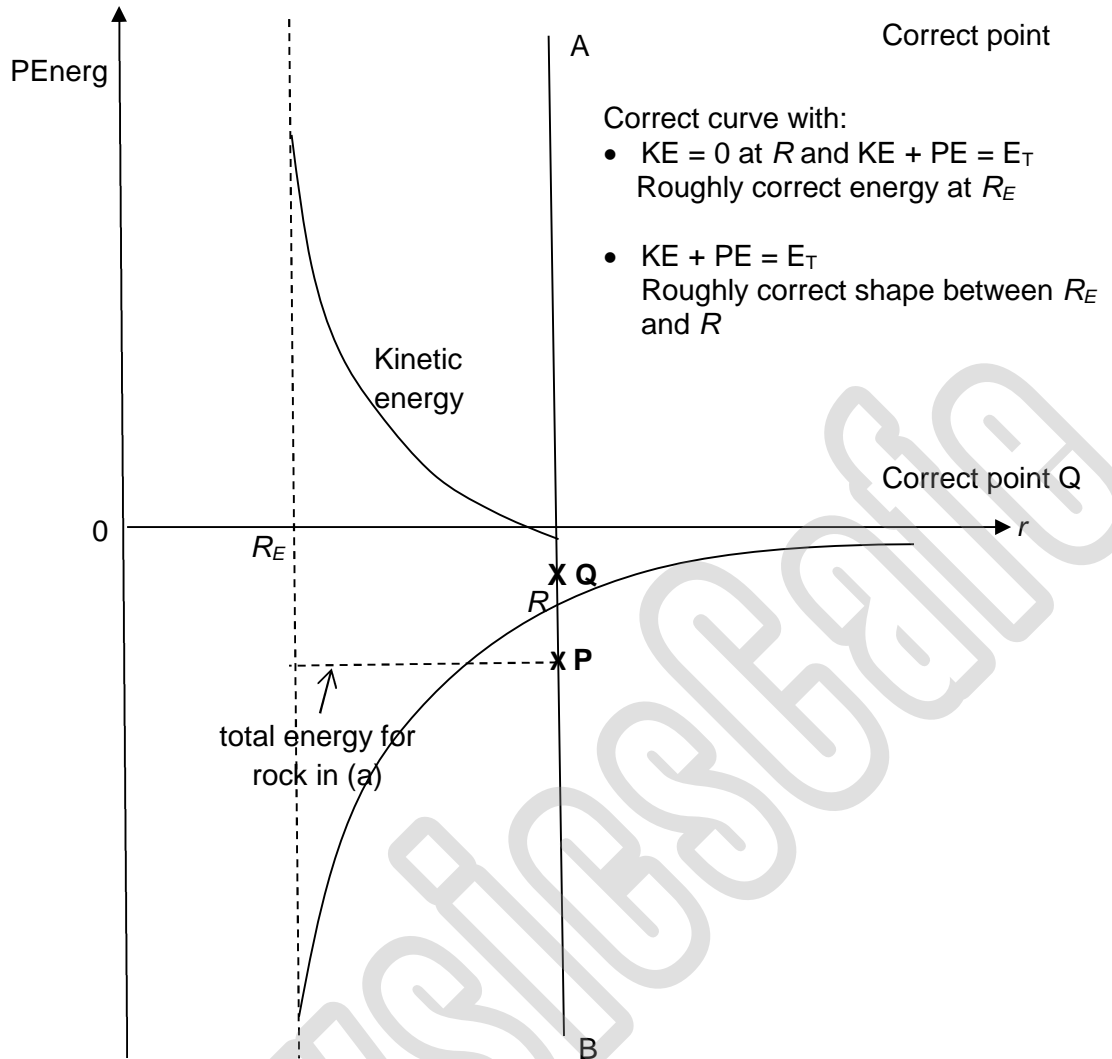
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..... [1]

Ans **ai**

**aii**



**3bi**

When the rock is momentarily at rest, KE is zero and total energy = GPE  
 (ai) Hence, total energy of rock is the intersection of line AB and GPE graph  
 (aii) At distance  $R$ , KE is zero. At distance  $R_E$ ,  $KE = \text{total energy} - GPE$

(bi) For a rock to escape to infinity with minimum speed, total energy at infinity is zero.

**bii**

Possible explanation includes

- Moon would attract the rock
- potential at Moon('s surface) is
  - not zero
  - less than 0
  - lower than at infinity
- moon is nearer; less gain in GPE from Earth to moon

Thus, escape speed would be lower.

2

(a) Define the terms *gravitational field strength*  $g$  and *gravitational potential*  $\phi$  at a point in a gravitational field.

(i) *gravitational field strength*  $g$

.....  
 ..... [1]

(ii) *gravitational potential*  $\phi$

.....  
 ..... [1]

(iii) Write down an expression that shows the relationship between the above two quantities with distance  $x$  from a point mass.

[1]

(b) The values for the gravitational potential due to the Earth are given in the table below.

Distance from Earth's surface / m	Gravitational potential / MJ kg <sup>-1</sup>
0	-62.53
290 000	-59.82
300 000	-59.73
310 000	-59.64
$\infty$	0

(i) If a satellite of mass **900 kg** falls from a height of **300 000 m** to the Earth's surface, how much potential energy does it lose?

potential energy lost = ..... J [2]

(ii) Deduce a value for the Earth's gravitational field strength at a height of **300 000 m**.

gravitational field strength = ..... N kg<sup>-1</sup> [2]

Ans (a)(i) Gravitational field strength at a point is defined as the **gravitational force per unit mass** acting on the object placed at the point. [B1]

(a)(ii) Gravitational potential at a point is defined as the **work done per unit mass by external agent** in bringing the mass from **infinity** to that point. [B1]

(a)(iii) 
$$g = -\frac{d\phi}{dx} \quad [B1]$$

Do not award if negative sign is absent.

(b)(i) Change in gravitational potential ( $\Delta\phi$ )

$$= \phi_{\text{final}} - \phi_{\text{initial}}$$

$$= [-62.53 - (-59.73)] \times 10^6$$

$$= -2.80 \times 10^6 \text{ J kg}^{-1} \quad [C1]$$

Change in potential energy for satellite

$$\Delta U = m \Delta\phi$$

$$= (900)(-2.80 \times 10^6)$$

$$= -2.52 \times 10^9 \text{ J}$$

Therefore, gravitational potential energy lost

$$= 2.52 \times 10^9 \text{ J} \quad [A1]$$

(b)(ii) 
$$g = -\frac{\Delta\phi}{\Delta x}$$

$$g = -\frac{[-59.82 - (-59.64)] \times 10^6}{[290\,000 - 310\,000]} \quad [M1]$$

$$= -9.0 \text{ N kg}^{-1}$$

Negative sign shows that  $g$  is acting in the direction of decreasing  $r$  (ie towards Earth).

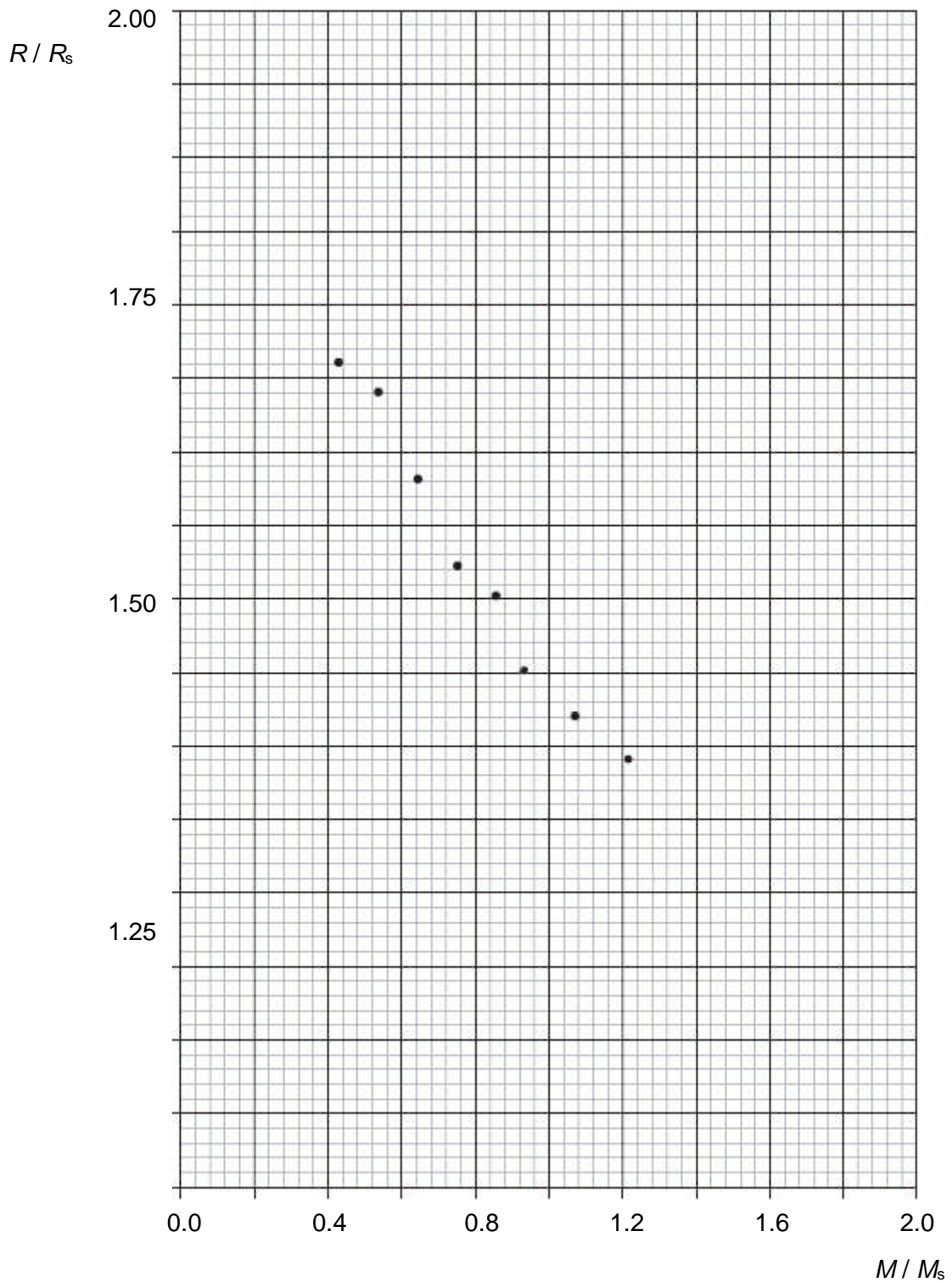
Taking just the magnitude

$$g = 9.0 \text{ N kg}^{-1} \quad [A1]$$

Can award 1M if student uses 300000 m and either (290000 m or 310000 m) to approximate the answer.

3

- (a) An astronomer is investigating the relationship between the radius  $R$  and mass  $M$  of eight different stars of the same species. The graph of the ratios  $R/R_s$  against  $M/M_s$  of these eight different stars are plotted in Fig. 2.1, where  $R_s$  and  $M_s$  are the Sun's radius and mass respectively.



- (i) On Fig. 2.1, draw the best fit line for the relationship between  $R/R_s$  and  $M/M_s$  for these stars. [1]

(ii) Determine the equation for this linear relationship. [2]

(iii) Estimate the maximum ratio of  $M / M_s$  for the mass of this species of star.

maximum ratio of  $M / M_s = \dots\dots\dots$  [1]

(iv) Suggest why your answer to (a)(iii) is only an estimate.

.....  
 ..... [1]

(v) Suggest and explain whether the Sun belongs to this species of stars.

.....  
 ..... [2]

(b) Fig. 2.2 shows the variation of the total gravitational potential with distance from the centre of one of the eight stars.  $R$  is the radius of the star which is **3300 km**.

Distance from centre of the star	Gravitational potential / MJ $\text{kg}^{-1}$
1.0 $R$	-13.5
1.5 $R$	-9.4
2.0 $R$	-7.2
2.5 $R$	-6.0
3.0 $R$	-5.2
3.5 $R$	-4.6
4.0 $R$	-4.2
4.5 $R$	-3.8
5.0 $R$	-3.5
5.5 $R$	-3.3
6.0 $R$	-3.0

Fig. 2.2



A rocket of mass  $1.2 \times 10^4 \text{ kg}$  lifts off from the surface of this star. Use Fig. 2.2 to  
**(i)** estimate the change in gravitational potential of the rocket at a distance  $3R$  above the surface of the star,

change in gravitational potential = .....  $\text{J kg}^{-1}$  [1]

**(ii)** estimate the minimum launch speed that the rocket must have in order to reach a height of  $3R$  above the surface of the star,

minimum launch speed = .....  $\text{m s}^{-1}$  [2]

**(iii)** estimate the magnitude of the gravitational field strength at a distance  $3R$  above the surface of the star.

gravitational field strength = .....  $\text{N kg}^{-1}$  [2]

- (iv) Student A claims that the gravitational field strength at any point above the surface of this star is not inversely proportional to the square of the distance from the centre of this star. Discuss the validity of this claim.

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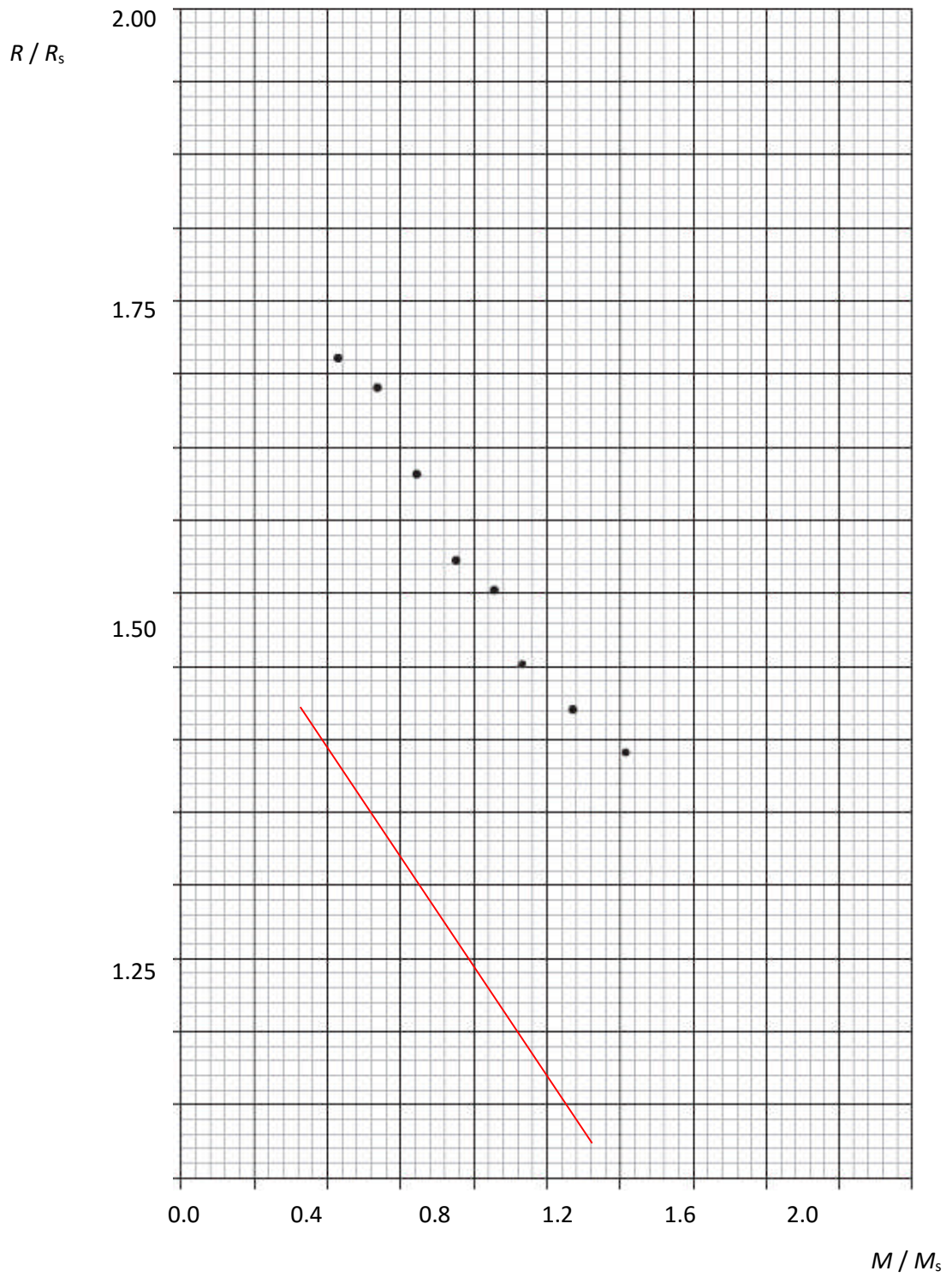
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.....

[2]

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Ans (a) (i)



Suitable BFL drawn

(ii) Gradient =  $-0.94 \pm 0.02$  [M1]  
 Y-intercept =  $1.80 \pm 0.02$

$$R / R_s = -0.94 (M / M_s) + 1.80 \quad [A1]$$

(iii)  $1.92 \pm 0.02$  [B1]

(iv) This value is obtained by extrapolation outside the data range and hence uncertainties are present. [B1]

or

The trend may not be a straight line beyond the set of data points given.

or

The maximum ratio corresponds to a star with zero radius hence this is not possible in reality.

(v) No, the Sun does not belong to this species of star. [A1]

The data point which represents the Sun on the graph is found at coordinates (1,1), which does not lie in the trend presented by the data points. [M1]

(b) (i) Change in gravitational potential =  $-4.2 - (-13.5) = 9.3 \times 10^6 \text{ J kg}^{-1}$  [B1]

(ii) Using conservation of energy,

Energy at surface = Energy at  $3R$  above surface

$$KE_R + PE_R = KE_{4R} + PE_{4R}$$

$$\frac{1}{2}mv^2 + m\phi_R = 0 + m\phi_{4R}$$

$$\frac{1}{2}v^2 = -4.2 \times 10^6 - (-13.5 \times 10^6)$$

$$v = 4.3 \times 10^3 \text{ m s}^{-1}$$

[M1]

[A1]

Allow ECF from (b)(i)

(iii) 
$$g = \frac{d\phi}{dr} = \frac{\Delta\phi}{\Delta r} = \frac{[-3.8 - (-4.6)] \times 10^6}{(4.5 - 3.5) \times 3300 \times 10^3}$$
 [M1]  

$$= 0.24 \text{ N kg}^{-1}$$

[A1]

(iv) The claim is valid. [A1]

The gravitational field strength at any point is a resultant of all the gravitational field strengths of this star and its neighboring stars. [M1]