A-LEVEL PHYSICS • EXERCISE SHEET

13.4 Gravitational potential

Name: ____________ Class: ________ Date: __________ **Total: 15 marks**

Objective

Build the skills to answer exam questions on **gravitational potential** —$\phi = -GM/r$ and gravitational potential energy.

You must be able to:

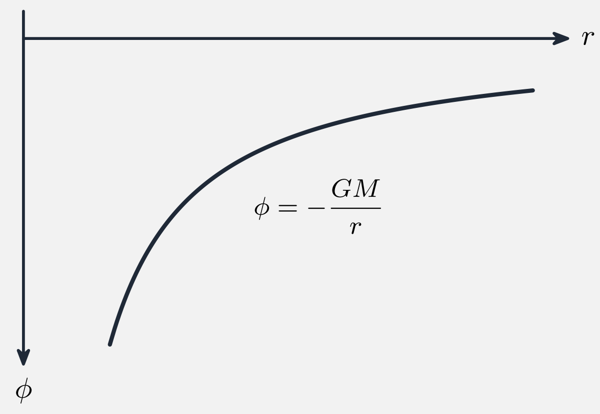
- define **gravitational potential** and use $\phi = -\dfrac{GM}{r}$
- use $E_\mathrm{P} = -\dfrac{GMm}{r}$ for two point masses
- explain why potential and E_P are negative

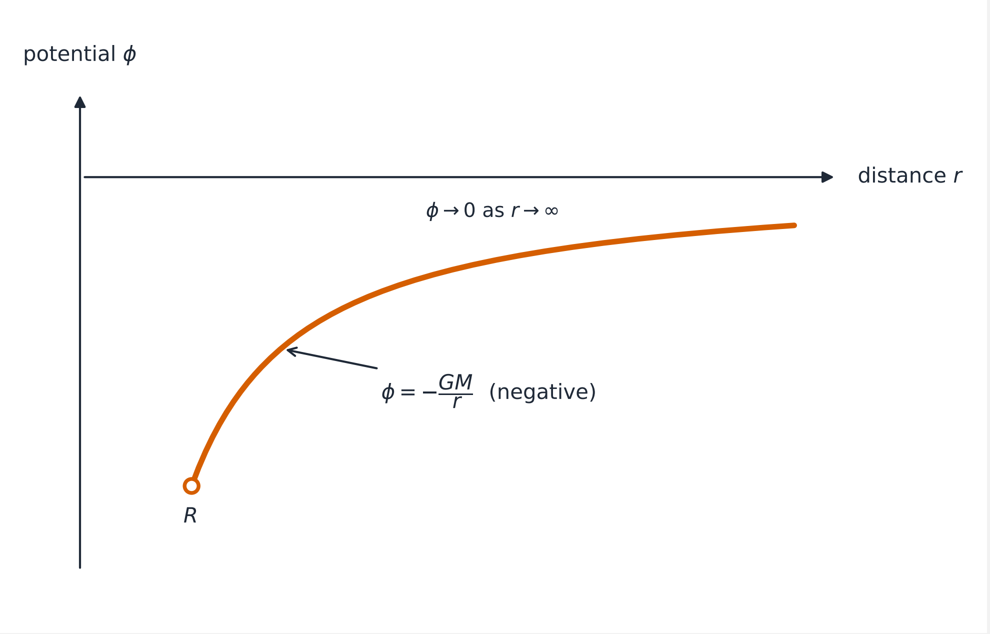
1 Worked examples

Study these first. Each one shows the method for a question type used later —follow the steps and you can do the Practice and Exam-style questions yourself.

■ Gravitational potential

Gravitational potential ϕ at a point is the **work done per unit mass** to bring a small test mass **from infinity** to that point. Potential is **zero at infinity** and **negative** everywhere else:





The gravitational potential well

$$\phi = -\frac{GM}{r} \quad (\mathrm{J\ kg^{-1}}), \qquad E_P = m\phi = -\frac{GMm}{r}.$$

For two radii, $\Delta E_P = GMm\left(\frac{1}{r_1} - \frac{1}{r_2}\right)$.

2 Practice

Now apply the methods above.

2.1 Define **gravitational potential**. [1]

2.2 State **why** gravitational potential is **negative**. [1]

2.3 State the unit of gravitational potential. [1]

2.4 Write the equation for the **gravitational potential energy** of two point masses. [1]

3 Exam-style questions

3.1 The gravitational potential at **infinity** is: [1]

- **A** a maximum positive value
- **B** zero
- **C** a large negative value
- **D** infinite

3.2 Calculate the gravitational potential at the Earth's surface. ($M = 6.0 \times 10^{24}$ kg, $R = 6.4 \times 10^6$ m, $G = 6.67 \times 10^{-11}$.) [3]

3.3 Calculate the gravitational potential energy of a 1200 kg satellite at $r = 7.0 \times 10^6$ m from the Earth's centre. [2]

3.4 Explain why **two closer** masses have **more negative** gravitational potential energy. [2]

3.5 A 1000 kg satellite orbiting a planet is moved from an orbit of radius 7.0×10^6 m to one of radius 1.4×10^7 m. Its gravitational potential energy **increases** by 2.86×10^{10} J. Calculate the **mass of the planet**, and give a **unit**. ($G = 6.67 \times 10^{-11}$.) [4]

4 Go further

You are now ready for the real exam questions on this subtopic. Open the **13.4 Gravitational potential** past-paper sheet in the Library, or try these in **Practice mode**:

- 9702/42 M25 —Q2 (find a planet's mass from a GPE change)
- 9702/41 J25 —Q1 (gravitational potential)
- 9702/43 J25 —Q1 (potential energy)
- 9702/44 J25 —Q1 (potential, structured)

Solutions

2.1 The **work done per unit mass** in bringing a small test mass from **infinity** to that point.

2.2 Gravity is **attractive**, so it does the work as the mass moves in from infinity (where $\phi = 0$); the potential therefore becomes **negative**.

2.3 J kg^{-1}.

2.4 $E_\mathrm{P} = -\dfrac{GMm}{r}$.

3.1 **B** —zero.

3.2 $\phi = -\dfrac{GM}{R} = -\dfrac{(6.67 \times 10^{-11})(6.0 \times 10^{24})}{6.4 \times 10^{6}} = -6.3 \times 10^{7}$ J kg^{-1}.

3.3 $E_\mathrm{P} = -\dfrac{GMm}{r} = -\dfrac{(6.67 \times 10^{-11})(6.0 \times 10^{24})(1200)}{7.0 \times 10^{6}} = -6.9 \times 10^{10}$ J.

3.4 As r decreases, $-\dfrac{GMm}{r}$ becomes **more negative**; the masses are more **tightly bound** —more work would be needed to separate them to infinity.

3.5 $\Delta E_\mathrm{P} = GMm\left(\dfrac{1}{r_1} - \dfrac{1}{r_2}\right)$; $\dfrac{1}{r_1} - \dfrac{1}{r_2} = \dfrac{1}{7.0 \times 10^{6}} - \dfrac{1}{1.4 \times 10^{7}} = 7.14 \times 10^{-8}$ m^{-1}; $M = \dfrac{\Delta E_\mathrm{P}}{Gm\left(\frac{1}{r_1} - \frac{1}{r_2}\right)} = \dfrac{2.86 \times 10^{10}}{(6.67 \times 10^{-11})(1000)(7.14 \times 10^{-8})} = 6.0 \times 10^{24}$ kg.