Topic 12: Gravitational Fields
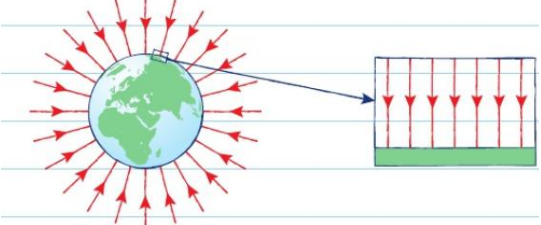
1.2 Specification notice:

Mathematical skills that could be developed in this topic include sketching relationships that are modelled by y = k/x, y = k/x².

12.Q Exam questions

12.174 understand that a gravitational field (force field) is defined as a region where a mass experiences a force

Define gravitational field (force field)?	A region of space where a mass experiences a gravitational force

12.175 understand that gravitational field strength is defined as $g = \frac{F}{m}$ and be able to use this equation

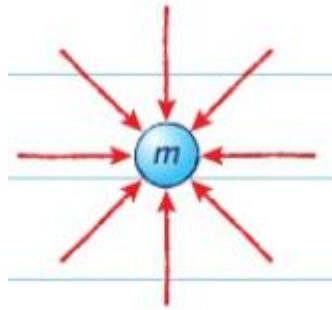| What is Gravitational Field Strength and what is the equation for it? (uniform field)	• It is the amount of force something would feel per unit mass (Nkg⁻¹). $$g = \frac{F}{m}$$ **Uniform gravitational fields** The field near the surface of a planet or star is approximately uniform. *g is the gravitational field strength (Nkg⁻¹), F is the force due to gravity (N), m is the mass of the object (kg)*

12.176 be able to use the equation $F = \frac{Gm_1m_2}{r^2}$ (Newton's law of universal gravitation)

| What is the definition of Newton's Law of Universal Gravitation and whats its equation? | **The gravitational force F between two masses (m$_1$ and m$_2$) is directly proportional to the product of the masses and inversely proportional to the square of the distance between them**

$$F = \frac{Gm_1m_2}{r^2} \textbf{ or } F = \frac{GMm}{r^2}$$

F is the force between the two objects (N), G is the gravitational constant 6.67x10^{-11} (also known as big G), m$_1$ and m$_2$ are the masses of the two objects are r is the distance between the centre of masses (m).
Big M is the mass that creates the g field

*A common mistake in exams is to forget to add together the **distance from the surface of the planet and its radius** to obtain the value of r.* |
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12.177 be able to derive and use the equation $g = \frac{GM}{r^2}$ for the gravitational field due to a point mass

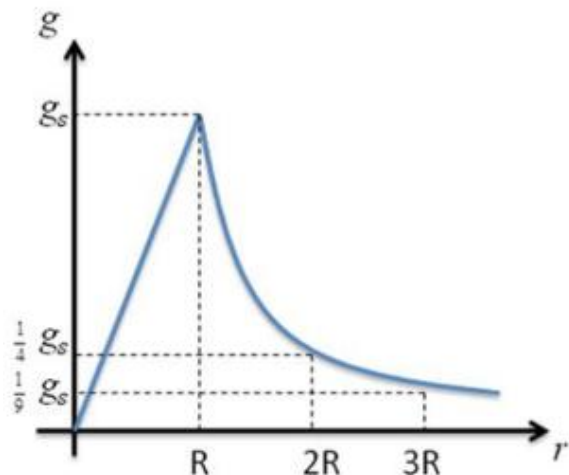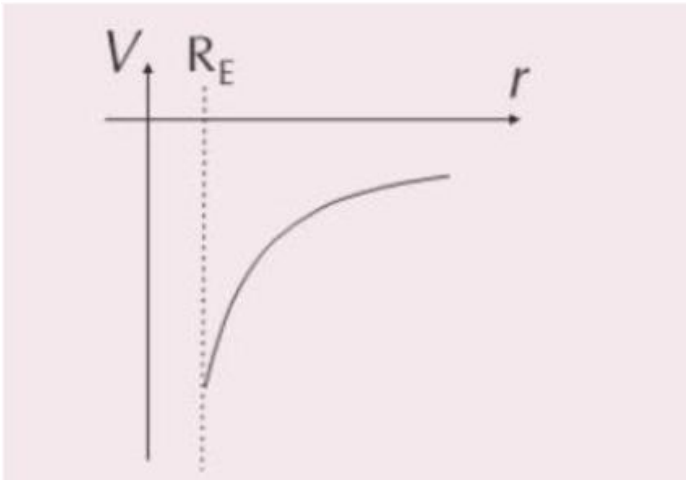|	
Derive the equation $g = \frac{GM}{r^2}$ for the gravitational field due to a point mass (radial field)	$F = mg, F = \frac{GMm}{r^2}$ $mg = \frac{GMm}{r^2}$ $g = \frac{GM}{r^2}$ *g is the gravitational field strength due to a point mass (Nkg⁻¹), G is the gravitational constant (big G), M is the mass of the object (like the Earth rather than the person, although you can do it vice versa) as gravitational field strength is independent of the mass, r is the distance from the centre of mass M* *When using the equation for gravitational field strength, remember that the mass M is the mass causing the gravitational field. The mass m is the object that experiences the gravitational field of M.*
What does the Gravitational Field Strength v. Distance graph look like and why?	The linear relationship at the start is because the mass below you is what matters (between the centre and r). By combining

	g=GM/r² and M=4/3πr³ρ, you get a linear relationship of g=4/3πGρr

12.178 be able to use the equation $V_{grav} = \dfrac{-Gm}{r}$ for a radial gravitational field

What is Gravitational Potential defined as, with its equation and why does it have a negative sign?	The work done per unit mass to move a mass from point to infinity OR The gravitational potential energy per unit mass (Jkg⁻¹) at a point $$V_{grav} = \frac{-Gm}{r}$$ *There is a negative sign as work needs to be done to move an object from a point in the field to infinity and so work is done against gravity as well as g is attraction so moving from point to infinity is opposite therefore its negative (since outside the field potential is defined as zero then the potential inside the field must be negative)* *Where V is the gravitational potential, G is the gravitational constant (big G), M is the mass of the object causing the gravitational field, r is the distance to that mass*
What is Gravitational Potential Energy defined as, its equation, and why is it negative?	The work required to move an object from a point (most likely earth) to infinity (where there is no potential). $$\Delta W = m\Delta V$$ which is from V=-GM/r and W=GMm / (1/r_b-1/r_a) $$\Delta V = -\frac{Gm}{r_2} - -\frac{Gm}{r_1}$$ $$\Delta V = GM(\frac{1}{r_2} - \frac{1}{r_1})$$ *When moving closer to a mass, positive work is done as GPE changes into KE. When moving away, negative work is done as its against the force of gravity (i.e., KE into GPE).*
What is the equation to calculate the escape velocity from a planet (e.g Earth)? [You don't need to know derivation but its good to remember]	1/2mv² = KE , ΔW=mΔV 1/2mv² = mΔV 1/2v² = ΔV - v=√2ΔV - v=√(2xGm)/r *Where v is velocity, V is the grav potential and its from*

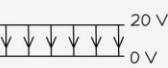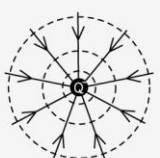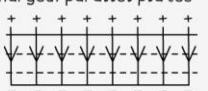|	this equation that we know the mass of an object m experiencing a force due to M does not effect the velocity of an object
What does the gravitational potential v. Radius graph look like?	If you find the **gradient** of this graph at a particular **point**, you get the value of g at that point. *If you find the gradient at a point, you get the value of g as $g = \frac{-\Delta v}{\Delta r}$ where the negative sign shows it acting in the opposite direction to gravitational potential.*

12.179 be able to compare electric fields with gravitational fields

What are the 10 differences/similarities between gravitational fields and electric fields	● Origin of force:

	Gravitational Fields	Electric Fields
Origin of the force	Mass	Charge
Force between two point masses/charges	$F_G = \frac{GM_1M_2}{r^2}$	$F_E = \frac{Q_1Q_2}{4\pi\varepsilon_0 r^2}$
Type of Force	Attractive force	Attractive force (opposite charges) Repulsive force (like charges)

Field Strength	$g = \dfrac{F}{M}$	$E = \dfrac{F}{Q}$
Field strength due to a point mass/ charge	$g = \dfrac{GM}{r^2}$	$E = \dfrac{Q}{4\pi\varepsilon_0 r^2}$
Field Lines	Around a point mass: In a uniform field (surface of a planet):	Around a (negative) point charge: −Q In a uniform field (between charged) parallel plates: 20 V 0 V
Potential	$V = -\dfrac{GM}{r}$	$V = \dfrac{Q}{4\pi\varepsilon_0 r}$
Equipotential Surfaces	Around a point mass: M In a uniform field (surface of a planet):	Around a point charge: Q In a uniform field (between charged) parallel plates + + + + + + + − − − − − − −
Work Done on a Mass or Charge	$\Delta W = M\Delta V$	$\Delta W = Q\Delta V$

They both follow the inverse square law is another similarity

12.180 be able to apply Newton's laws of motion and universal gravitation to orbital motion.

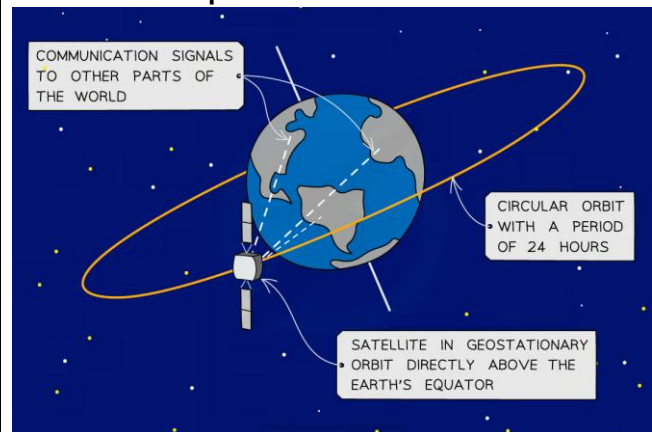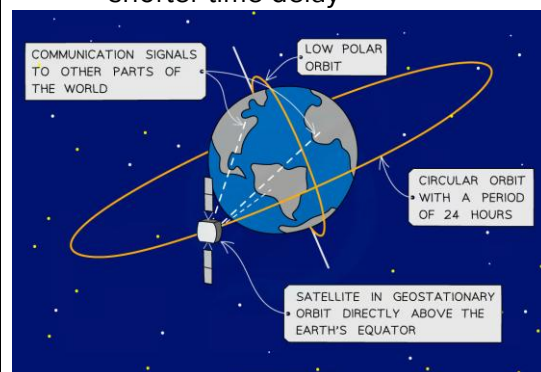|	
What are the 2 types of orbits that satellites and planets can do around objects? What is the advantage of satellites doing an Elliptical orbit instead (2)?	Elliptical orbit ● Allows satellite to get closer to surface so more detailed photographs/scans possible (2) ● Allow satellite to spend time further from the surface so prevents exposure to prolonged heat from planet damaging probe (2) ● Satellite varies distance from surface so it can take wide angle and close up pictures of the planet (2) Circular orbits ● Explained on other FC below!
Describe the 2 different types of circular orbits that satellites do and their purpose?	Geostationary orbit - occurs above the Earth's equator ● Where a satellite would always be above the same point on the Earth's surface (1) ● So that contact/communication with e.g the space station would be maintained at all times (1) ● It has a **period of 24 hours** Close Polar orbit (or low orbit) ● Where a satellite would always be above the north and south poles of the Earth ● Used for monitoring weather, military applications and taking images of Earth's surface, as there is a shorter time delay *Geostationary occurs at 36000km and polar at 360km above sea level*

How can Time period and orbital radius for a satellite in circular orbit be derived?	By equating the centripetal force and gravitational force and approximating the orbit as circular
	$$F_c = F_G$$ $$m_{sat} \frac{v^2}{r} = G \frac{m_{sat} M}{r^2}$$ $$v^2 = G \frac{M}{r}$$ $$\left(\frac{2\pi r}{T}\right)^2 = G \frac{M}{r}$$ $$\frac{4\pi^2 r^2}{T^2} = G \frac{M}{r}$$ $$\frac{r^3}{T^2} = G \frac{M}{4\pi^2}$$ Also $T^2 = \frac{4\pi^2 r^2}{GM}$ to find orbital period Also v = 2πr/T The ratio (r^3/T^2) will be a constant value for all satellites of the same central body, for example all planets orbtiting the sun it only depends on the mass producing the grav field