9.2.1 Gravity

The Earth has a gravitational field that exerts a force on objects both on it and around it

Prerequisite Knowledge (of Physics and KC Notes)

- **SI Units**: kilograms, metres, seconds, make sure they are changed before calculations
- Some equations **derived** from those that appear in the formulae sheet need to be **memorised**
- Headers (column 1 of syllabus), Dot Points (column 2), Practicals (column 3), Formulae

1.1 Define **weight** as the force on an object due to a gravitational field

- **Mass (kg)**: quantity of matter in an object
- **Weight (N):** force that acts on an object due to a gravitational field
- Objects are commonly measured from their **centre**

$$\boldsymbol{F = mg}$$

F = force/weight (N), m = mass (kg), g = gravitational acceleration (9.8ms^{-2} on earth)

- **Newton's Law of Universal Gravitation**: force of attraction between two masses (relies on distance/mas s)

$$\boldsymbol{F = G\frac{m_1 m_2}{d^2}}$$

F = force (N), G = gravitational constant (6.67×10^{-11} N m^2 kg^{-2}), m_1, m_2 = masses (kg), d = distance between masses (m)

- **Gravitational acceleration** of a planet is independent of the object's mass – a satellite will experience the same gravitational acceleration as a coin.
  - Combining **force/mass** formula with **force between two objects** formula
  - Note the difference between **force** and **acceleration**!

$$\left(\cancel{m}g = G\frac{m_1 \cancel{m_2}}{d^2}\right) \rightarrow \boldsymbol{g = \frac{GM}{d^2}}$$

g = gravitational acceleration (ms^{-2}), G = gravitational constant, M = mass of planet (kg), d = distance from planet's **centre** (m)

1.2 Explain that a change in **gravitational potential energy** is related to **work done**

- **Gravitational potential energy** (GPE, E_p): **energy stored due to its position** in a gravitational field
  - Converted to kinetic energy when it falls
- **Work**: force acting on an object causing it to move, $W = F \times s$
  - Work done to an object lifted up is **stored** until it is released, i.e. $E_p = W$
  - Therefore, substituting F = mg and s = height (i.e. force an object upwards)

$$(W = Fs) \rightarrow \boldsymbol{E_p = mgh}$$

E_p = gravitational potential energy (J), m = mass (kg), g = gravitational acceleration (ms^{-2}), h = height from **centre** of planet

1.3 Define **gravitational potential energy** as the work done to move an object from a very large **distance** away to a point in a gravitational field

- g is not always constant as it **depends on height**
- Sub in $g = \frac{GM}{r^2}$ from 1.1:

$$\left(E_p = m\frac{GM}{r^2}h\right) \rightarrow \boldsymbol{E_p = -G\frac{m_1 m_2}{r}}$$

E_p = gravitational potential energy, m_1, m_2 = mass, G = gravitational constant, r = distance from centre of circle

- E_p is **negative**
  - By definition, at an **infinite distance, E_p is zero**
  - Therefore, as an object falls/enters gravitational field, E_p is **converted to KE** and is therefore negative
  - Can also be explained as **$\Delta KE = -\Delta E_p$**, therefore $\Delta KE + \Delta E_p = 0$ and so ΔE_p must always be negative
- Change in E_p (ΔE_p) is always **positive**
  - Measured by subtracting based on radius: $E_p = -Gm_1m_2(\frac{1}{r_1} - \frac{1}{r_2})$; $r_1 > r_2$

1.P1 Perform an investigation and gather information to determine a **value for acceleration due to gravity using pendulum motion** or computer-assisted technology and **identify reason for possible variations from the value 9.8ms^{-2}**

- A pendulum with 20g mass is attached to a retort stand and time is recorded for it to travel 10 oscillations.
- The period (seconds per oscillation) measured.
- $T = 2\pi\sqrt{\frac{l}{g}}$ is used to determined gravitational acceleration
- **Accuracy**: human reaction time for stopwatch, 10 oscillations to increase accuracy, use data loggers
- **Validity**: value of g affected by altitude, spinning Earth, friction, see 1.P2

1.P2 Gather secondary information to **predict the value of acceleration due to gravity on other planets**

- Acceleration due to gravity (g) can be determined by **mass and radius of a planet**
  - $g = G\frac{M}{d^2}$, measured in **ms^{-2} downwards**
- Various **variations in gravitational acceleration** is due to:
  - **Altitude:** Further away, less gravity (mountains, valleys, satellites)
  - **Local crust density:** more dense, more gravity
  - **Oblation**/shape: greater radius at equator than poles

1.P3 Analyse information using the expression: $\boldsymbol{F = mg}$ **to determine the weight force** for a body on **Earth** and for the same body **on other planets**

- Use $F = mg$ and:
  - $g = 9.8ms^{-2}$ for Earth or $g = G\frac{m}{d^2}\ ms^{-2}$ for other planets