WJEC A-Level Physics

4.3 Orbits and the Wider Universe

Flashcards

What is Kepler's first law?

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Kepler’s first law states that *the orbit of a planet is an ellipse, with the sun at one focus.* The eccentricity of the ellipse is very low, so the motion can be modelled as circular.

What is Kepler’s second law?

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Kepler's second law states that *a line segment joining a planet and the sun sweeps out equal areas during intervals of equal time.* This is because the speed of the planet is not constant – the planet moves faster when it is closer to the sun.

What is Kepler’s third law?

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Kepler's third law states that *the square of the orbital period T is proportional to the cube of the average distance r from the sun.* This can be proved by considering the forces acting on the planet. Centripetal force is required to keep the planet in orbit, and this force is provided by the gravitational field of the sun.

Derive this equation to show T^2 is proportional to r^3 and explain your steps

$$T^2 = \frac{4\pi^2 r^3}{GM}$$

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1. Because of Kepler's third law, we can equate the formula for centripetal force with the formula for gravitational force to get **$mv^2/r = GMm/r^2$**
2. Rearrange to get **$v^2 = GM/r$**
3. Since velocity in circular motion is **$2\pi r/T$**, you can substitute this into the previous equation to get **$4\pi^2 r^2/T^2 = GM/r$**
4. Rearrange this to get **$T^2 = 4\pi^2 r^3 / GM$**

What is Newton’s law of Gravitation?

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Newton's law of gravitation states that two point masses attract each other with a force that is directly proportional to the product of their masses, and inversely proportional to the square of the distance between them.

$$F = \frac{GMm}{r^2}$$

What are satellites? What are they used for?

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- Satellites are objects that orbit other, larger objects. These can include natural satellites like the moon, and artificial satellites that humans have sent into space.
- Uses include: communications, scientific research, and Global Positioning Systems (GPS).

What are geostationary satellites? What are they used for?

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- Geostationary satellites have an orbital period that is exactly a day, so that they appear stationary above the Earth.
- They orbit 36,000km above the equator.
- They are useful for communications and surveying as they provide continuous coverage.

What is the period of a geosynchronous orbit?

What is the period of a geosynchronous orbit?

Geosynchronous orbits have a period of one day.

How is the orbital period related to the radius of a circular orbit?

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$$T^2 \propto R^3$$

What equations could you use to find the speed of an orbiting satellite?

What equations could you use to find the speed of an orbiting satellite?

The orbiting object (mass m) is in circular motion, so we would use $F=ma$ with $F=GMm/r^2$ rearranged to $a = v^2/r = \omega^2/r$. This can be solved to find the speed (v), angular speed (ω), the radius of the orbit or using $T=2\pi/\omega$, its period.

What equations could you use to find the the mass of the central object given orbital speed and time period?

What equations could you use to find the the mass of the central object given orbital speed and time period?

Kepler's third law

$$T^2 = \frac{4\pi^2 r^3}{GM}$$

$v = \omega r$ $\omega = 2\pi/T$

And rearrange for M

$$M = \frac{4\pi^2 (v/\omega)^3}{GT^2}$$

What is dark matter and what evidence is there for it?

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When we estimate the mass of a galaxy (using luminosity) and use it to estimate its orbital speed, the estimated value is different to the actual speed it is travelling at. This means that there must be more mass than we can see. This is known as dark matter.

Scientists believe the Higgs boson may be related to dark matter - they are seeing if it can decay into dark matter via supersymmetry.

What is the Doppler effect?

What is the Doppler effect?

The change in wavelength and frequency of a wave as the source moves away or towards the observer.

As the source moves towards the observer, the waves are compressed and the wavelength decreases. As the source moves away from the observer, the waves spread out and the wavelength increases.

What is redshift?

What is redshift?

Redshift (z) is the shift in wavelength and frequency of waves from a retreating source towards/beyond the red end of the electromagnetic spectrum. Cosmological red shift is evidence for the Big Bang.

The formula for redshift can only be used when v is much smaller than c (the speed of light).

$$\underbrace{z}_{\text{Redshift}} = \frac{\overbrace{\Delta f}^{\text{change in frequency}}}{\underbrace{f}_{\text{original frequency}}} = \frac{\overbrace{v}^{\text{velocity of object}}}{\underbrace{c}_{\text{speed of light } 3\times10^{8}\,ms^{-1}}} = \frac{-\overbrace{\Delta\lambda}^{\text{change in wavelength}}}{\underbrace{\lambda}_{\text{original wavelength}}}$$

State Hubble's law.

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The velocity of receding galaxies is proportional to their distance from Earth.

$$v = H_0 d$$

v = velocity of a retreating galaxy (km s^{-1})
d = Distance from Earth (Mpc)
H_0 = Hubble's Constant = 65 km s^{-1} Mpc^{-1}

Use Hubble's law to estimate the age of the universe.

Use Hubble's law to estimate the age of the universe.

Time = distance / velocity = 1 / H_0 (since $v = H_0 d$)

The units of Hubble's constant must be converted to SI units

65 km s^{-1} Mpc^{-1} x10^3 gives **H_0 = 65,000 m s^{-1} Mpc^{-1}**

Divide by 1 Mpc (**3.08 x 10^{22} m**) to get the units for H_0 as s^{-1}

H_0 = 2.11 x 10^{-18} s^{-1} so **1 / H_0 = 4.74 x 10^{17} s**

Age (convert to years) = 4.74 x 10^{17} / 3600 / 24 / 365 = **1.5 x 10^{10} years (or 15 billion years).**

What is the critical density and how do you calculate it?

What is the critical density and how do you calculate it?

- The density required for the universe to be flat is called the critical density, p_c

If you let p_0 be the average density of the universe, then the following is true:

- $p_0 = p_{c,}$ ➜ then the universe is flat
- $p_0 < p_{c,}$ ➜ then the universe is open
- $p_0 > p_{c,}$ ➜ then the universe is closed
- And the equation for the critical density is

$$\rho_c = \frac{3H^2}{8\pi G}$$