11/11/25

Gravity

Physics

Context

- Newton, who discovered gravity, also posed his famous thought experiment about orbiting satellites.
- You are also required to know the formula for gravity, as well as its effects in the formation of stars and its importance in the slingshot effect.

Definitions

- Gravity - an attractive force between any and all massive particles

Equations

- Gravitational force - $F = \frac{GMm}{r^2}$
  (where G is the gravitational constant, $6.67 \times 10^{-11} m^3 kg^{-1} s^{-2}$)

Technique

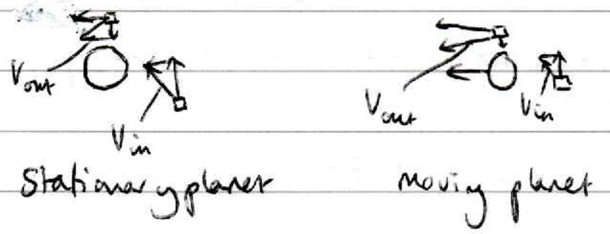
- Gravity equation:
- A planet of mass 83×10^{23} kg and radius 3000km has a rocket fly past it. At its point closest to the surface of the planet, the 96 Mg rocket is 340 km above the planet's surface. What is the force of gravitational attraction at this point?
- $F = \frac{GMm}{r^2}$
- $F = \frac{6.67 \times 10^{-11} \times 83 \times 10^{23} \times 96\,000}{(3340 \times 10^3)^2} = 4\,800\,000$ J

- Newton's Thought Experiment -
  if a cannonball was fired off the top of a mountain, it would travel a distance before gravity pulled it to the ground.
  if the cannonball were fired faster, it would remain in the air for longer
  however, at some speed it would keep curving, and missing, and therefore falling continually

- (cont.) its speed would remain the same, but as its direction changes, it accelerates (remember, acceleration is a vector and therefore has a direction) to match the curvature of the earth therefore, this satellite remains in orbit
- Gravity in the formation of stars
  - when gravity pulls together matter (hydrogen and helium) it fights a battle against the thermal forces produced by nuclear fusion in the formation of stars.
  - Stars are first produced when their gravitational force causes them to contract, creating the pressure required for fusion to begin
- The Slingshot Effect
- ~~Base~~ Space probes are difficult to accelerate of their own volition, so in order to bring them up to speed they utilise the gravity of a planet

As they approach the planet, its gravity pulls the probe inwards, accelerating it.

If the planet were stationary then the probe would decelerate by the same amount as it left the planet - but instead, because of the planet's relative velocity, the resultant velocity of the planet is greater.



Thing to Remember

- Gravitational constant = 6.67×10^{-11} (remember Dr Mackie going '6 7')
- ~~Projectiles~~ Satellites curve towards the earth at the same rate as the earth's curvature, hence why they don't fall. (or rather, are constantly falling?)

Special Relativity

12/11/25 Physics

Context

- Einstein postulated his theory of Special Relativity in 1905, the same year he published his papers on the photoelectric theory and black body radiation.
- Based on the idea that all motion is relative, Einstein made two postulates that allowed him to ascertain strange behaviours that occur when an object is in motion (though these are only relevant at high speeds)

Definitions

- Einstein's first postulate - the speed of light is the same for all observers, regardless of reference frame
- Einstein's second postulate - the laws of Physics are the same in all frames of reference.

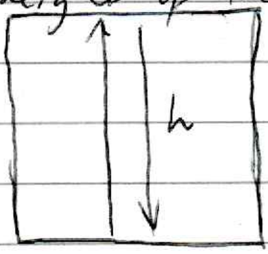
Equations

- The Lorentz Factor - $\frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}$
- Time dilation - $t' = \frac{t}{\sqrt{1 - \frac{v^2}{c^2}}}$
- Length contraction - $L' = L\sqrt{1 - \frac{v^2}{c^2}}$

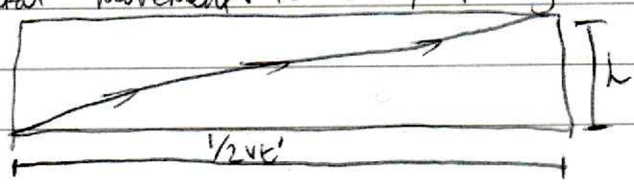
  where t & L are the 'actual' time and length, & t' and L' are the observed time and length by an observer on earth

Technique

- Proof of time dilation:
- First imagine you bouncing a beam of light, while inside a train. From your reference frame this takes $2h/c$, where h is the height of the cabin.



- On the other hand, an observer on the platform sees a horizontal movement. For them, the light travels the hypotenuse of a right triangle



- By Pythagoras, we can find this d in terms of v, c, t, and t' - which is the dilated time that will be required for this scenario to not be self-contradictory.
- $d^2 = \left(\frac{vt'}{2}\right)^2 + h^2$

$\left(\frac{ct'}{2}\right)^2 = \left(\frac{vt'}{2}\right)^2 + \left(\frac{ct}{2}\right)^2$

$t'^2c^2 = v^2t'^2 + t^2c^2$

$t'^2(c^2 - v^2) = t^2c^2$

$t' = \sqrt{\frac{t^2c^2}{(c^2-v^2)}}$

$t' = \frac{t}{\sqrt{1-\frac{v^2}{c^2}}}$

- Now using this formula to solve a question:
- A spaceship travels at 86% the speed of light past earth. The captain, an avid jogger, takes 20 minutes to do a lap of the ship. How long does he take according to a stationary observer on earth?
- $t' = \frac{t}{\sqrt{1-\frac{v^2}{c^2}}}$

$t' = \frac{20}{\sqrt{1-0.86^2}} = 20/0.51 = 39.2$ minutes

Thing to Remember

- Relativistics only applies at speeds of at least $0.1c$.
- t' and l' are the observed time and length
- Einstein's postulates are the speed of light remaining constant & that physics works the same in all frames of reference. Length contraction and time dilation are the effects.