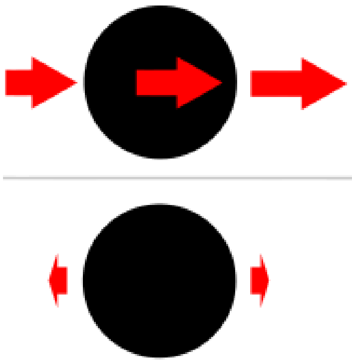
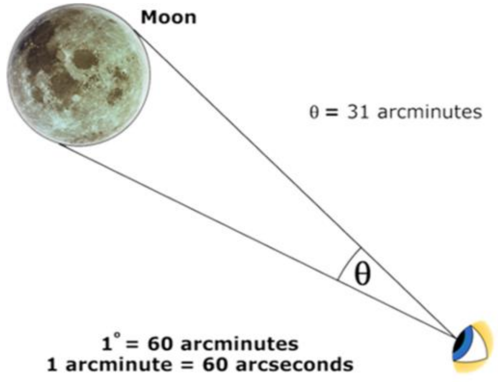
Astronomy **Summary Knowledge Organiser** – Chapter 10 (Topic 3) **The Earth-Moon-Sun system (i)**

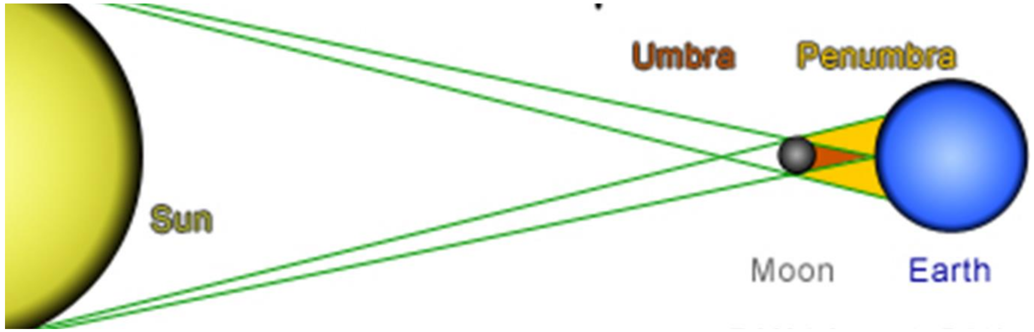
Tidal forces – due to **Newton's inverse square law of gravitation** the size of the **FORCE APPLIED** to an object decreases rapidly as the **DISTANCE** between two objects increases! This has serious consequences for small moons that orbit large planets.

Tidal forces from large planets can **stretch small moons across the middle** causing **INTERNAL TIDAL HEATING**. Due to the inverse square nature of gravity a **host planet will pull the near side of a moon with more force than its far side**. The effect is the same as if the moon had **two equal and opposite forces pulling on its sides**, it will stretch and elongate across its middle (see diagram right).



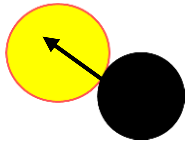
By cosmic coincidence the Sun and Moon both appear the same size when viewed from Earth, they both have ANGULAR DIAMETERS of 0.5°.





Solar eclipses – occur at **NEW MOON** when the Moon passes directly between the Earth and the Sun. Because the Moon **casts a SMALL SHADOW on the Earth** and the fact that the **EARTH SPINS QUICKLY on its axis**, places on the surface pass into and out of the shadow in only a **FEW MINUTES**. If the observer is watching the eclipse from within the **PENUMBRA** they will see a **PARTIAL solar eclipse**. A lucky few in the **UMBRA** will see a **TOTAL solar eclipse** when at totality the Sun's photosphere is completely hidden and so the **CHROMOSPHERE & CORONA can be seen.**

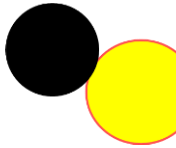
Tidal forces acting on Earth (due to the interaction of the gravitational forces of the Moon and Sun) **cause two tidal bulges to form in the oceans** on the Earth's surface. As Earth spins parts of the coast experience **twice-daily HIGH & LOW TIDES.**



First contact – when the Moon's disk first comes into contact with the Sun's disk.

Second contact – when the whole of the Moon's disk covers some or all, of the Sun's disk.

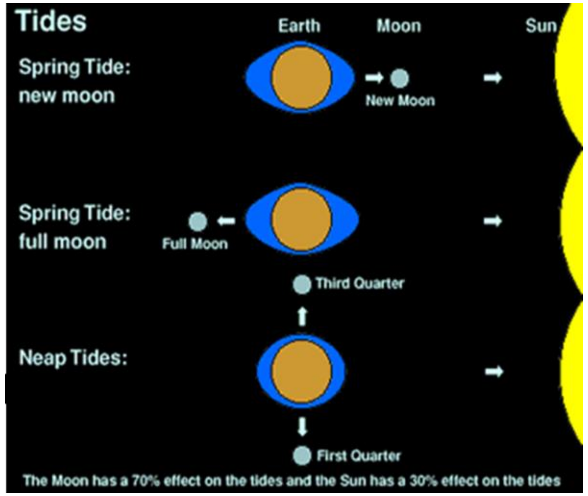
Third contact - when the edge of the Moon's disk comes back into contact with the edge of the Sun's disk.



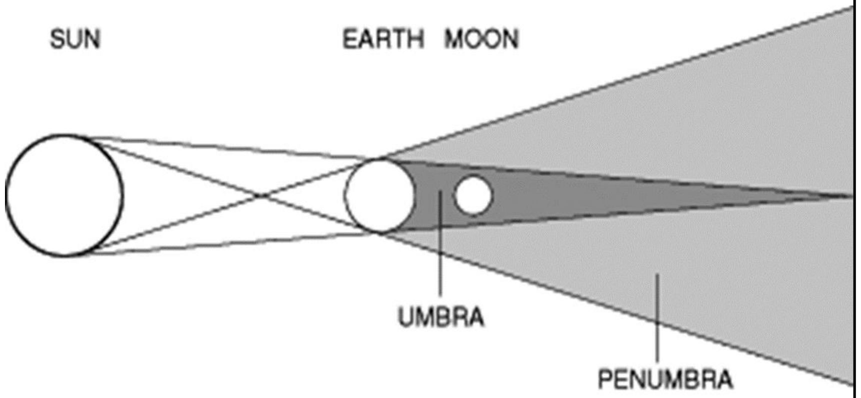
Fourth contact - when the Moon's disk loses contact with the Sun's disk.

If the Moon & Sun are **very high & low SPRING tides** will be caused aligned (at **new** & **full moon**).

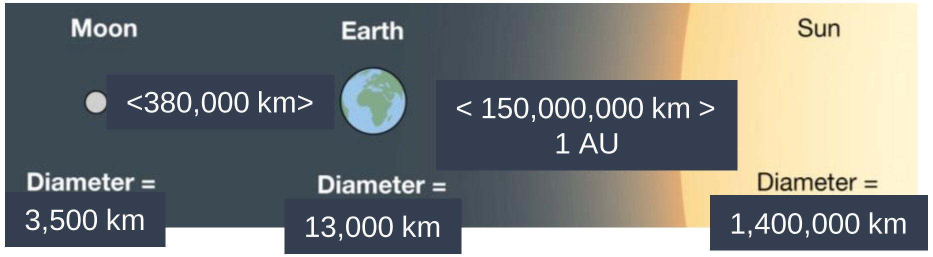
NEAP tides (less dramatic sea-height variations) occur when the Moon & Sun's tidal forces act at right angles to each other.



Lunar eclipses – occur at **FULL MOON** when the **Moon passes through the Earth's shadow**. If the Moon passes into the **Earth's UMBRAL shadow** a **TOTAL lunar eclipse** will be seen. If the Moon lies in the **UMBRAL shadow** only a **PARTIAL lunar eclipse** will be seen. Due to the **LARGE SIZE of the Earth's shadow** lunar eclipses can **last up to 3 HOURS**. At **TOTALITY** the Moon looks **COPPER/RUST-RED in colour** because light from the Sun passes through the Earth's atmosphere and **red light is mainly REFRACTED** onto the Moon's surface (**blue light** is also largely **scattered** by the Earth's atmosphere so it doesn't reach the Moon).



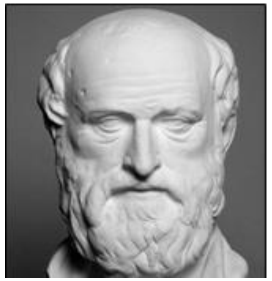
Astronomy **Summary Knowledge Organiser** – Chapter 10 (Topic 3) **The Earth-Moon-Sun system (ii)**

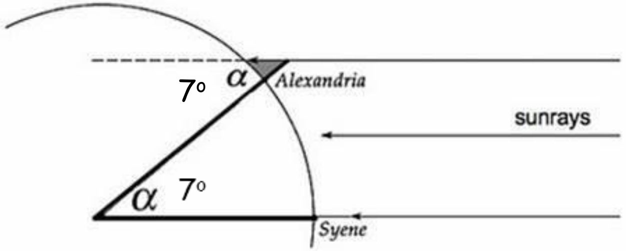


1 : 4 : 400
ratio of diameters

The **ancient Greeks** applied geometrical skills to determine firstly the **scale** of the E-M-S system and then eventually **Eratosthenes** and **Aristarchus** calculated the **actual size** of the system.
ERATOSTHENES calculated the **CIRCUMFERENCE if the Earth**! He found out that on one day a year **at noon** (the **summer solstice of June 21st**) the **Sun was directly overhead** (at the zenith) of a **deep water well** in the city of **Syene** and so sunlight reached the very bottom of the well! He also realized that on the same day in **Alexandria** (a city further North) **columns did cast shadows** and so the Sun was clearly **not directly overhead**.
Eratosthenes placed a vertical pole in the ground at Alexandria and by measuring the **height of the pole** and **length of the shadow** it cast at noon on June 21st he was able to calculate the **angle between the Sun and the vertical**. The value of this angle was **7 degrees** (**1/50th of 360°**).
He then calculated the circumference of the Earth using the following formula (after he'd estimated the distance between the 2 cities);

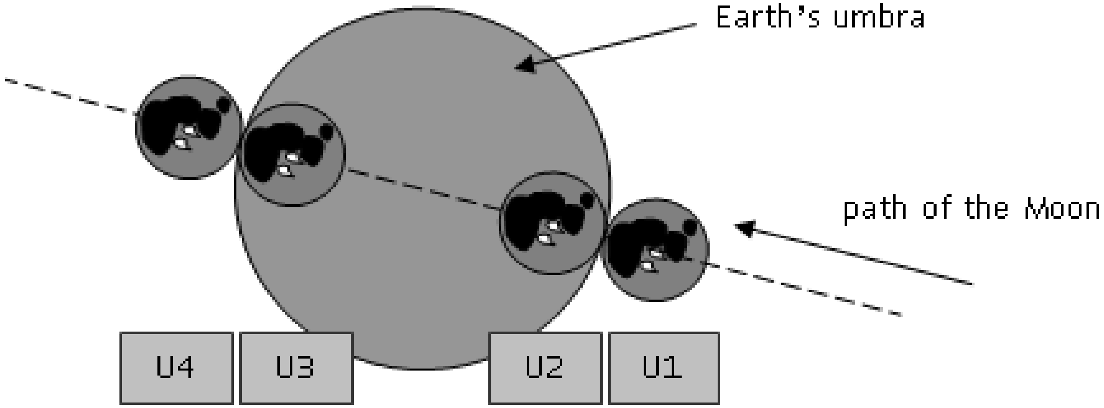
$$\frac{\text{Circumference of the Earth}}{\text{Distance from Syene to Alexandria}} = \frac{360^\circ}{7^\circ}$$





The first break through of **ARISTARCHUS of Samos** was to determine the **RELATIVE DIAMETER of the Moon compared to Earth** using observations of **TOTAL LUNAR ECLIPSES**.

He made the assumptions that the Sun was so far away that rays of sunlight travelled in parallel lines therefore the diameter of the **Earth's shadow umbra must be equal to the diameter of the Earth**, that lunar eclipses occurred when the Moon passed into the Earth's umbra and thirdly that if the Moon passed straight through the middle of the umbra the distance it travelled would be equal to the diameter of the Earth!
He then observed an eclipse and recorded the **time taken** for the Moon to travel from **U1 to U2** (giving a value of the Moon's diameter) and the time taken for it to travel through the whole umbra from **U2 to U4** (giving a value of the Earth's diameter). From these values he estimated that the **Moon's diameter was between 0.32 and 0.40 times that of the Earth.** True modern day value = **0.27 times.**



The diagram shows the full Moon in four key positions during a lunar eclipse.
Astronomers refer to these as the first umbral contact (U1) to the fourth umbral contact (U4).

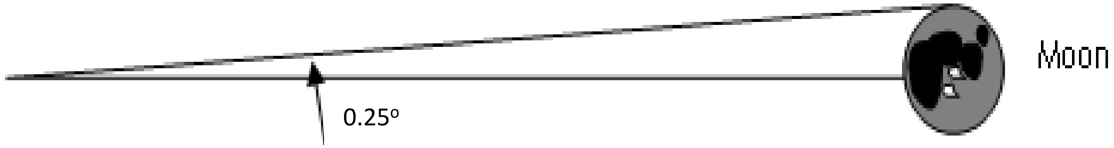
Later, the **actual diameter of the Earth** was determined by Eratosthenes and from it the **Moon's actual (absolute) diameter** could then be calculated.

Looking at the formula to the right, it is clear that knowing all 3 values except for the one top right, means that the 'diameter of Moon' can be calculated.

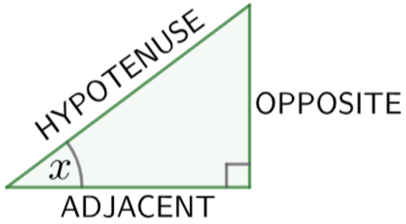
$$\frac{\text{U1 to U2}}{\text{U2 to U4}} = \frac{\text{diameter of Moon}}{\text{diameter of Earth}}$$

Astronomy **Summary Knowledge Organiser** – Chapter 10 (Topic 3) **The Earth-Moon-Sun system (iii)**

Next, the Greeks decided to focus on determining the **MOON'S DISTANCE from Earth**. Aristarchus used a very **simple method** for this task – he knew that when he observed the night sky his thumbnail was just big enough to cover the Moon's disc, if he held it at arms length. So, by measuring the **length of his outstretched arm** and the **width of his thumb**, he could easily use his knowledge of triangles to calculate the **angular size** of his thumb, which was the same as the angular size of the Moon. Now he knew the **diameter of the Moon** and the **angular size of the Moon** he applied a simple knowledge of triangles to calculate the Moon's actual distance from Earth!

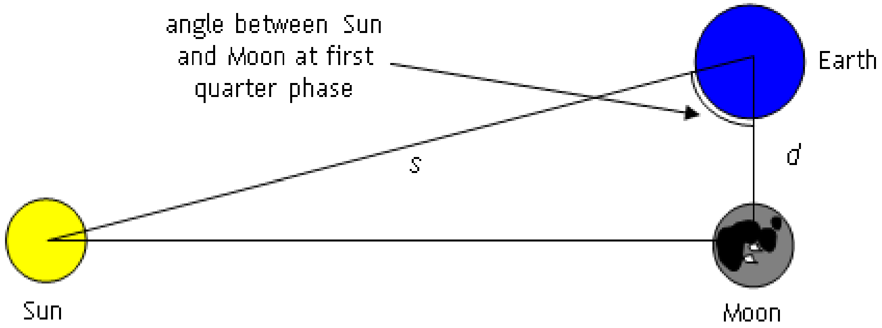


If you know the value of the **OPPOSITE** (Moon's radius) and the value of **angle *x*** then we can calculate the value of the **ADJACENT** (distance between Earth and the Moon)

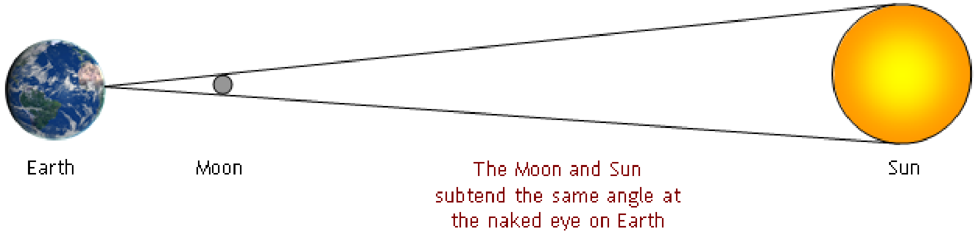


Aristarchus estimated that the **Moon's angular size was 2°** (it is **actually 0.5°**), this was **surprisingly inaccurate**.
It is difficult to believe that Aristarchus could be out by a **factor of 4 but** perhaps the Moon appeared larger than usual when he did his observations due to some unknown atmospheric effect or perhaps Aristarchus was more concerned with his methodology rather than the accuracy of his measurements. We simply don't know!

Next, Aristarchus set out to find the **DISTANCE to the SUN**. He did this by working out the RELATIVE distances of the Sun and Moon from the Earth. If he could work out how many times further away from Earth the Sun was, compared to the Moon, he could simple times the known Earth-Moon distance by that value, to calculate the distance to the Sun. Aristarchus waited until the Moon was exactly at its **FIRST QUARTER PHASE**.
He measured the **angle between the Sun and the Moon** on this day to be **87°** (the true value of the angle is 89.853°). This angle meant that the **Sun must be 20 times further away** from Earth than the Moon.



Aristarchus had clearly made errors in some of his measurements or assumptions and later in 1630, Vendelinus used a telescope and measured the angle at first quarter phase to be 89.75° which suggested the Sun was 230 times further away then the Moon. Clearly, this is much closer to the **true value of '400 times further'**. The <u>inaccuracies</u> of Aristarchus's calculations are probably due to the great **<u>difficulties of precisely measuring angles in the sky that are close to 90°</u>**.



Finally, Aristarchus knew that the Sun had almost exactly the same angular size as the Moon (the ancient Greeks knew this from simply observing **TOTAL SOLAR ECLIPSES**, see image left). Because of this, the **DIAMETER of the SUN** could easily be calculated – if they had the same angular size and you already knew how many times further away the Sun was than the Moon (distance from Earth ratio), their **relative diameters** would have the same ratio. Since Aristarchus thought the Sun was 20 times further away from the Earth than the Moon he calculated that the Sun must have a diameter 20 times larger!