3.The Earth-Moon-Sun System (3.1-3.4)

Edexcel GCSE Astronomy Course

3.1 Be able to use the relative sizes of the Earth, Moon and Sun

3.2 Be able to use the relative distances between the Earth, Moon and Sun

The table comes from this website which has a lot of really useful scale information about planets and moons in the Solar System: https://britastro.org/node/13975

Object	Eq. Diameter (km)	Scale Diameter (mm)	Diameter Relative to Earth	Radius of Orbit (km)	Scale Orbital Radius (mm)	Orbital Radius Relative to Earth
Earth	12,756	5.0	1.0x	149,600,000	58,639	11,728x
Moon	3,475	1.4	0.27x	384,000	151	30x
Sun	1,391,016	545.2	109.1x	-	-	-

Tasks you could try:

- Use numbers in column 2 to check that column 4 is correct e.g. Moon Diameter/Earth Diameter = 0.27
- Use numbers in columns 2 and 5 to check that column 7 is correct ((Column 5/Earth Radius) =Column 7)
- Use the scale values in column 3 to draw/cut out circles representing relative sizes of the three objects
- Use the scale values in column 6 to measure out a relative distance scale - you will need a length about half the size of a soccer pitch to do this!
- Use this NASA worksheet to make an Earth-Sun model https://sunearthday.nasa.gov/2007/materials/solar_pizza.pdf

3.3 Understand how Eratosthenes and Aristarchus used observations of the Moon and Sun to determine successively: a diameter of the Earth b diameter of the Moon c distance to the Moon d distance to the Sun e diameter of the Sun

To start off with, just watch this really excellent explanation of what Eratosthenes did over 2000 years ago and be amazed:

https://www.youtube.com/watch?v=Mw30CgaXiQw

If you know anyone who lives at a significantly different latitude you could collaborate to recreate the experiment - and you don’t have to do it on June 21st, it just means the geometry is different.

So, how can we go from that to items a, b, c, d and e on the specification item 3.3 list above?

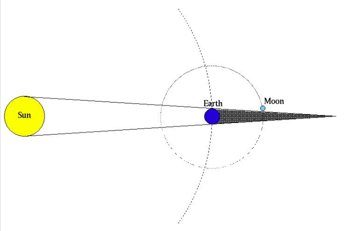
3.3a is relatively straightforward, Eratosthenes got Earth’s circumference and diameter = circumference/π

Aristarchus’s methods relied on slightly more complicated geometry but are equally impressive ideas given the lack of technology available to make direct measurements at the time.

3.3 continued: How Aristarchus used observations of the Moon and Sun to determine b diameter of the Moon c distance to the Moon

Aristarchus used two basic methods, one based on measuring angles between Moon and Sun and one based on observing lunar eclipses (where the Earth's shadow passes across the Moon): You have got to really enjoy geometry to follow all the steps, but this is a good explanation of how he estimated the radius of the Earth to be 3.7 times the radius of the Moon using the shadow of a lunar eclipse (**3.3b diameter of the Moon)**
https://www.eg.bucknell.edu/physics/astronomy/astr101/specials/aristarchus.html

His method for finding **3.3c distance to the Moon** depended on measuring how long the longest lunar eclipses lasted - basically just using a speed = distance/time calculation where the Moon's orbital speed was circumference divided by 30 days and circumference is 2π x radius and radius is the distance between Earth and Moon. By comparing this estimate of orbital speed with distance divided by time as the Moon passed through Earth's shadow, he estimated the Moon's distance to be 60 times the radius of the Earth which was pretty good! The maths is explained well here https://www-spof.gsfc.nasa.gov/stargaze/Shipprc2.htm



3.3 continued: How Aristarchus used observations of the Moon and Sun to determine d distance to the Sun e diameter of the Sun

Aristarchus estimated **3.3d distance to the Sun** using a measurement of the angle between Moon and Sun at half Moon - this came to between 18 to 20 times the distance to the Moon, a serious underestimate as it turned out.

He realised that the angular size of the Moon and the Sun in the sky were roughly the same i.e. the Moon's disc would precisely cover the Sun's disc if directly in front of it. This was a good assumption and is the reason we can experience solar eclipses from time to time on Earth. From this, he reasoned that the Sun must therefore be 18 to 20 times larger than the Moon if it was 18 to 20 times further away - again a serious underestimate, but good geometry. That's **3.3e diameter of the Sun**

These methods are explained in detail on this Wiki page:

https://en.wikipedia.org/wiki/On_the_Sizes_and_Distances_(Aristarchus)

In the GCSE course you won't have to explain all the geometry of these methods but you might be expected to do some calculations using simplified versions of some of them. It's probably best to see some questions and to try out some calculations to help you to understand how this all worked even 2000 years ago.

Examples of calculations based on the methods of Eratosthenes and Aristarchus (1)

Question:

Around 200 BCE, the Greek astronomer Eratosthenes heard that the Sun was directly overhead at midday on June 21st in the southern Egyptian city of Syene.

*Observing the Sun on June 21st in Alexandria, in the north of Egypt, he found that it was **not** directly overhead at midday.*

He used these observations to prove that the Earth was a sphere.

Explain, using a carefully-labelled diagram, how these observations prove that the Earth cannot be flat.

So, to answer this question, you need to watch the earlier video again very carefully, stopping it where necessary, then sketch and label a diagram showing how the curvature of the Earth would lead to a change in the angle of the shadow stick with the Sun's rays coming from directly above the stick at Syene at midday on June 21st. (Incidentally, what does that tell you about the latitude of Syene if the Sun is exactly overhead at midday on the summer solstice?) https://www.youtube.com/watch?v=Mw30CgaXiQw

Examples of calculations based on the methods of Eratosthenes and Aristarchus (2)

Question:

The Greek astronomer Aristarchus made observations of the Moon at the First Quarter phase. He measured the angle between the Moon and the Sun when the Moon was at the First Quarter phase. His measurements are summarised in the table.

Angle between Moon and Sun (°)
87
89
86
85
88

From these measurements he calculated that this angle was 87°, which meant that the Sun was 19 times further from the Earth than the Moon.

From earlier observations, he had also calculated that the distance between the Earth and the Moon was 175 000 km.

Analyse Aristarchus' observations and calculate a value for the distance from the Earth to the Sun.

(Total for question = 2 marks)

The best way to solve this problem is to start with a sketch, labelled with the information given in the question. This will help you to see what you are being asked to do more clearly. (Hint - don't worry about the angle!)

Examples of calculations based on the methods of Eratosthenes and Aristarchus (3)

Question:

The Greek astronomer, Aristarchus, calculated the diameter of the Sun from measurements of the apparent size of the Sun's disc. He found that the diameter of the Sun was 28 times smaller than the distance from the Earth to the Sun. He used a value for the Earth–Sun distance of 65 million km. Using these data he calculated 2.3 million km for the diameter of the Sun whereas modern measurements give 1.4 million km.

(i) Calculate the percentage error in his value for the diameter of the Sun.

$$\%\ \text{error} = \frac{(\text{calculated diameter} - \text{true diameter})}{\text{true diameter}} \times 100$$

Answer .... ***(2)***.

(ii) *Aristarchus' value of the diameter of the Sun is different from the true value.*

*Explain **one** reason for this.* ***(2)***

...

...

... ***(Total for question = 4 marks)***

3.4 Be able to use information about the mean diameter of the Sun (1.4×10^6 km)

This site has a good range of useful and interesting information about the Sun:

https://www.space.com/17001-how-big-is-the-sun-size-of-the-sun.html

Any calculations involving the Sun are going to involve BIG numbers. Be careful when manipulating these. You could use information from this website to calculate things like the density of the Sun or to check relationships between radius, surface area and volume using the equations for dimensions of a sphere $4\pi r^2$ and $4/3\pi r^3$

These links are also interesting to look at to get information about the scale of the Sun:

https://solarsystem.nasa.gov/solar-system/sun/overview/

https://nssdc.gsfc.nasa.gov/planetary/factsheet/sunfact.html

Answers to the exam questions:

(1)

Question number	Answer	Acceptable Answers	Marks
	Clear labelled diagram showing curved Earth with two locations marked. *Explanation or diagram establishes that:* Light rays from Sun are parallel So differing angles at two locations can only happen on a curved Earth.		1 1 1

(2)

Question number	Answer	Mark
	3 300 000 (km) *Allow:* 3 325 000 (x 19 = 1)	**(2)**

Answers to the exam questions:

(3)

Question number	Answer	Additional guidance	Mark
(i)	Difference in diameters (1) 2.3 million km – 1.4 million km = 0.9 million km Express as a percentage of true value (1) $\left(\frac{0.9}{1.4}\right) \times 100 = 64\%$	Award full marks for correct numerical answer without working Accept values that round to 64%	(2)

Question number	Answer	Additional guidance	Mark
(ii)	An explanation that combines identification – understanding (1 mark) and reasoning/justification – understanding (1 mark): The angular size of the Sun was determined incorrectly (1) because (unaided) observation near the Sun is very difficult/dangerous due to very high brightness (1)	Reject: he miscalculated/made an error in his calculation	(2)