1. Harrison, in Chapter 1 (*Introducing the Masks*) of his book *Masks of the Universe,* draws a sharp distinction between Universe (with a capital 'U') and universe(s) – explain why he considers this essential, and would you agree with Harrison that "the Universe lies beyond the reach of human comprehension"?

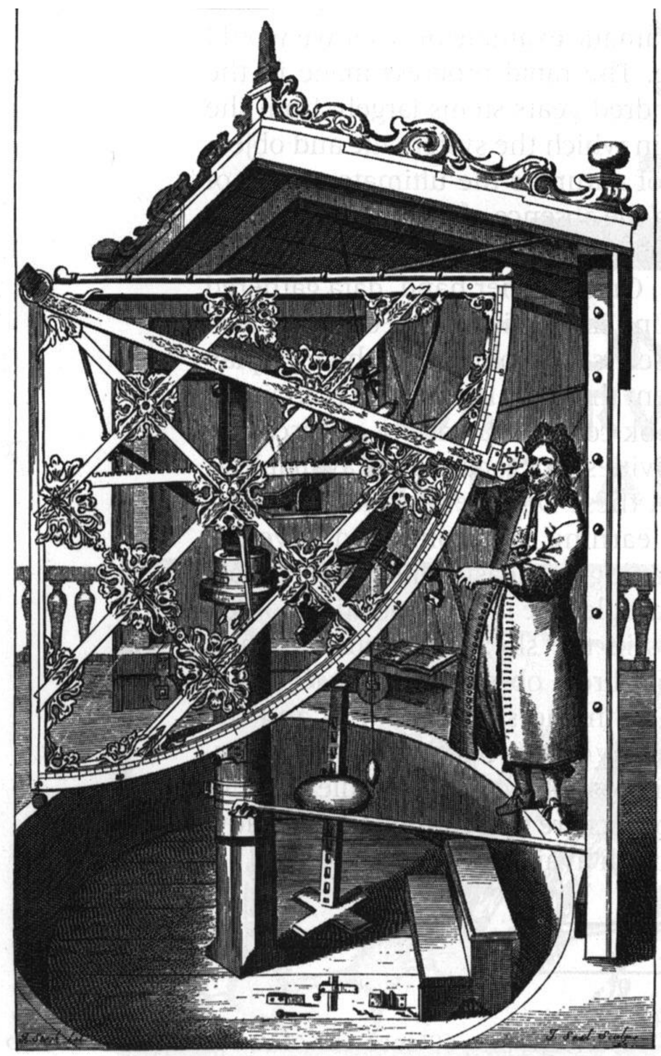
2. In Chapter 1 (*What is Cosmology?*) of his book *Cosmology: The Science of the Universe*, Harrison discusses, what he terms, the "anthropometric universe" – explain what you understand by this, and how it differs from both the "anthropomorphic" and "anthropocentric" universes?

3. Two observers, A and B, are 300km apart. They both observe an object S. Observer A is sure that angle BAS is exactly 85°. Observer B however, knows only that angle ABS lies somewhere between 88° and $88^\circ\ 30'$. In what range is the distance BS? Why is it important to use a baseline AB which is as long as possible?

4. a) How far away from your eye should you hold a coin of diameter 1cm so that it just covers the disc of the full Moon?

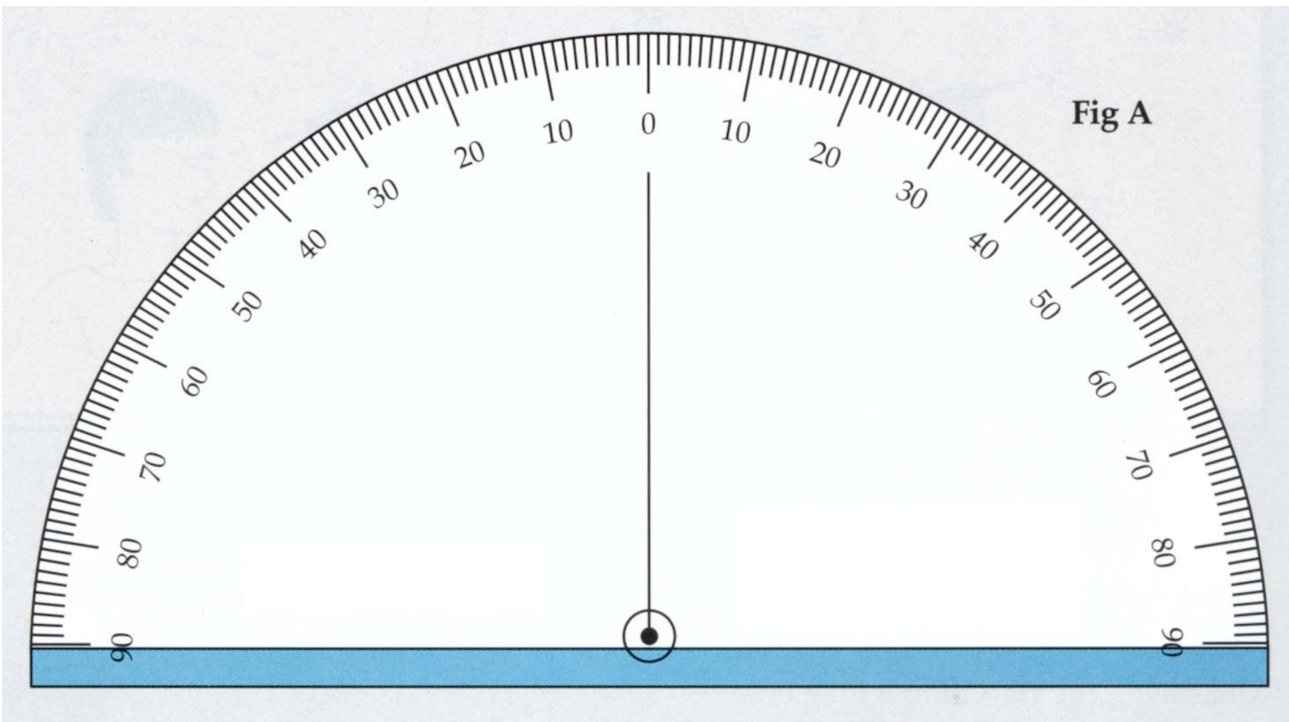
b) What can you infer about the relative sizes of the Sun and Moon and their relative distances from Earth by noting that we can observe **total** solar eclipses?

The quadrant (illustrated on the right) was a mechanical device developed by astronomers of the past to measure altitudes of planets and stars above the horizon. A variant, the sextant, is used for navigation by ships at sea (although these days, GPS or global positioning by satellite is obviously a more accurate and efficient modern method).



GROUP PROJECT ASSIGNMENT (Questions 5 & 6): single written submission per group, and groups may be asked to present their findings during a tutorial

Following the instructions set out below, make a rudimentary quadrant and use it to answer questions 5 and 6. You will need some stiff paper or thin cardboard measuring about 20 cm x 11 cm, a straw, some thread or twine and a small weight or bob.



Assembly instructions:

a. Copy or cut out Fig A (after scaling/adjusting it to be about the same dimensions specified above for the cardboard/stiff paper) and glue the two together.

b. Punch a hole through the cardboard/stiff paper at the point marked

c. Tie the weight (eraser, metal nut etc.) to one end of a 30 cm long thread.

d. Pull about 2 cm of the other end of the thread through the hole in the stiff paper and tape it to the back of the paper.

e. Tape the straw to the stiff paper so that its edge is exactly along the shaded part of the protractor. Ensure that the weight and string are able to hang freely.

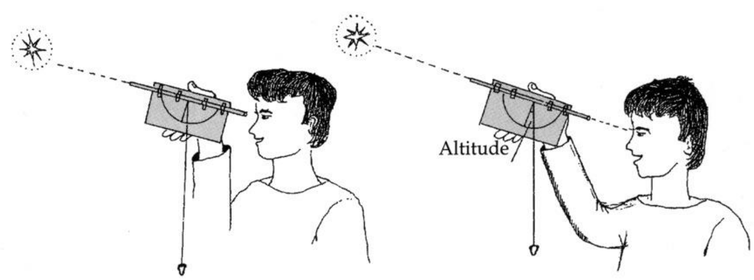
<u>How to use it</u>:

You can use your quadrant to find out how many degrees the Moon or a particular star moves across the night sky in one hour. It can also be used in daylight to measure the height of tall objects.

Hold your quadrant so that the string hangs freely along the side of the protractor as shown below.

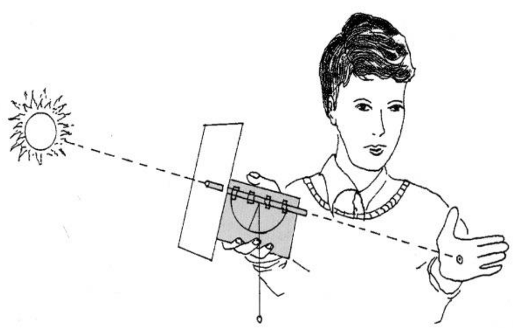
Look for the Moon (or a star) and sight through the straw. You might try holding the quadrant either close to your eye or at arm's length when sighting.

When the object is sighted through the straw, press the string against the protractor and read off the number of degrees. This will equal the altitude of the celestial object.



<u>WARNING</u>: DO NOT LOOK DIRECTLY AT THE SUN THROUGH THE STRAW (NOT EVEN WITH DARK GLASSES) AS IT MAY PERMANENTLY DAMAGE YOUR RETINA.

You can however use your quadrant to estimate the altitude of the sun at various time of the day by modifying it as follows:



Push the front portion of the straw of your quadrant through another piece of stiff cardboard paper. Point the straw at the sun until a bright spot of light appears on your hand as shown in the diagram and read of the number of degrees shown on the protractor by the thread. This gives the altitude of the Sun.

5. Triangulation is a useful method to determine the position of a point that is not accessible to direct linear measurement. Organizing yourselves into groups, locate yourself at approximately the centre of Town Green, facing the U Town Residence. On a site map of U Town, indicate the location you have selected.

The objective is to determine the height of the south tower (the one with the NUS logo at the top) to within an accuracy of, say, about 5 meters.

First, using triangulation, derive an analytic formula for the height of the tower. Then, with the quadrant you have constructed, measure the relevant elevation angles which occur in your formula. You will also need to make at least one distance measurement for which you will need either a tape measure (say, of length 5 to 10 m) or an equivalent length of string plus a meter ruler. **Note that, when making ANY of your measurements, you MUST NOT get**

any closer than 50m to the base of the building (nor are you allowed to use Google Maps etc. to determine heights).

Make a list of the possible measurement errors that could affect the *accuracy* of your answer, distinguishing between systematic and random errors and address how you have accounted for the corresponding uncertainties. Discuss reasonable ways of estimating the relative size of such errors – in other words, how confident are you that the final value your group obtains is indeed within a margin of say, 5 meters of the actual height of the tower?

6. a) The Moon is, on average, some 384,400 km distant from the Earth, and at this time of the month we are nearing the lunar phase of a full moon. Using your quadrant, try to measure the altitude of the Moon (the number of degrees that it is above the horizon).

b) Next, can you estimate the actual diameter of the Moon? If you do not succeed, why not? Can you think of ways of modifying or improving your instrument in order to allow you to obtain a more meaningful result?

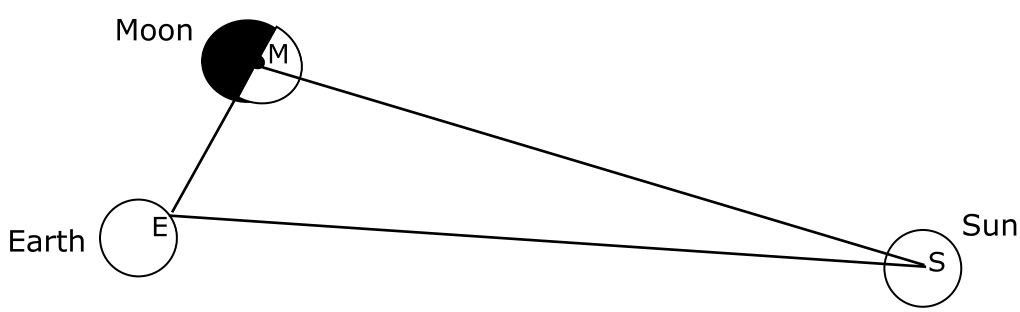
7. a) What phenomena would you expect to see in the sky if you were observing from a flat Earth? A round Earth?

b) Suppose the Earth were shaped like a discus or a Frisbee, which when seen from the Moon is observed edgewise. What shape would the Earth's shadow be on the Moon if a lunar eclipse took place at sunset?

8. An observer at A notes that a vertical stick 2.74m high casts a shadow of length 1m. At the same time, at B, 555km to the north, a stick of height 2.58m casts a shadow of length 1.2m. Deduce a value for the radius of the Earth.

9. You can watch the Sun set and disappear over a calm sea, once while you lie on the beach, and once again if you then immediately stand up. Say that you measure the time between these two 'sunsets' as 11.1 sec. Assuming your height to be 1.7 m, obtain a value for the radius of the earth. How *accurate* is the value you have obtained?

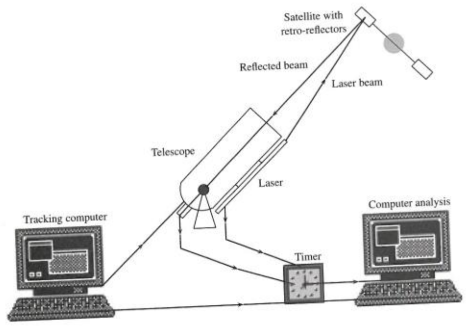
10. During the 2nd century B.C. Aristarchus of Samos (now more famous for his anticipation of the Copernican system) estimated the ratio of the distances to and the sizes of the Sun and Moon by measuring the angle (MES) subtended by the centres of the Sun and Moon at the earth see the diagram below which is not drawn to scale) when the Moon is exactly half full.



Aristarchus obtained the angle MES to be 87° and concluded that the Sun was therefore 19 times further away from the earth than is the Moon and that the Sun was also 19 times larger than the Moon. Can you reconstruct his argument? [*Note that, compared to modern measurements made by quite different techniques and with the aid of telescopes, Aristarchus' value was too small by a factor of around 20.*]

The preceding yields only the ratios of astronomical distances, but by an immensely ingenious argument, Aristarchus was able to convert them to absolute values, or in other words, he was able to determine the absolute distances to and diameters of the Sun and Moon (in units known as *stades*, where one *stade* is about 185 meters). He managed to obtain these results just by making observations of a lunar eclipse of maximal duration – how was he able to obtain these results?

11. These days we have of course compelling direct evidence that the Earth is spherical from orbiting satellite photographs; while satellite laser ranging (SLR) allows us to accurately measure the size as well as the shape of the Earth with great precision.



Shown at the left is a simple SLR system. A transmitter sends a short pulse of laser light to a satellite from which *retro-reflectors* bounce the beam back to a receiver, mounted alongside the transmitter. An event timer, driven by an atomic clock, measures the 'time-of-flight' of the signal. Atomic clocks can measure the round-trip time to an accuracy of 50 picoseconds (50×10^{-12} seconds) or better. Since we know the speed of light (299,792,458 m/s), it is a simple matter to obtain the distance between the laser beam transmitter and the satellite.

In fact, a similar set-up (with retro-reflectors placed on the Moon) allows scientists to continuously track the distance between the earth and the Moon to sub-centimeter accuracy!

As far as measuring the size and shape of the Earth with this technology is concerned, a single distance measurement is not particularly useful. However, combining measurements from different SLR stations located around the world provides a wealth of valuable information. Do some research on the web to find out about the SLR technique. Explain clearly how such measurements can be usefully combined and then briefly discuss some of the different types of geophysical information that become accessible using SLR.