Lifelong Learning Programme

Unit title	Jupiter and its moons
Topic	Astronomy
Name and email address of person submitting unit	Not available
Aims of Unit	To discuss key concepts such as day length and periodicity, students must calculate day length, the occurrence of eclipses and the time taken during an orbit.
Indicative content	Orbit, eclipse and astronomical calculations
Resources needed	The students will need access to the papers either in printed hard copy or in electronic form.
Teachers notes	This is a challenging main activity suitable for post 16 students and should take approx. 45 minutes. This is a very interesting main activity which challenges pupils to conduct some detailed calculations and also consider the implications of these calculations. Learning outcomes for this activity All pupils will be able to use data to discuss theories which are proposed in the presentation. Most pupils will be able to use the data and specimen calculations provided to calculate orbit times related to the moons of Jupiter. Some Use data and instructions provided to predict scale and speed on an astronomical scale.

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Date:	Topic: Jupiter and its moons	Time: 45 minutes	Class: 16+

SEN pupils

Gifted and Talented

Class Room Support

Equipment needed for this activity:

Health and Safety:

Learning outcomes for this activity

All pupils will be able to use data to discuss theories which are proposed in the presentation.

Most pupils will be able to use the data and specimen calculations provided to calculate orbit times related to the moons of Jupiter.

Some Use data and instructions provided to predict scale and speed on an astronomical scale.

Starter Activity
Main Activity Pupils are given a text to follow which has embedded within it information, tables and specimen calculations. Pupils are encouraged to follow examples and instructions to complete tables and eventually calculate distance and velocity. Pupils are required to think in terms of planetary movement and speed of light.
Plenary Activity

Reflections on the lesson

Jupiter and its Moons

Scientists spend a lot of time collecting evidence about the way our Universe works. This involves making detailed observations from which predictions can be made and tested, and new facts discovered. Very often scientists use observations by other people to make predictions and test them. Using other scientists work is a skill that has to be developed.

This investigation is about you using other scientists work to find out something about the way light moves. Your aim is to get a value for the speed of light from data about the moons of Jupiter. You should learn some other things about how scientists work in doing this. Firstly you should see that scientists often discover things which are not to do with the original aim of an investigation. Secondly you should realise that the results of scientific investigations are not always generally accepted, and it may take time for that to happen.

There is not a lot of equipment needed for this investigation. In fact you could repeat the original observations with a good pair of binoculars and a watch! You will have to do some careful measurements of distances, some scale drawing calculations, some calculations of times when a calendar might be useful, and throughout a calculator will be needed.

Read through the article Jupiter and its Moons – A Clock in Space. There are a series of questions in bold and you should answer them in order as you read through the article.

Jupiter and its Moons – A Clock in Space

Scientific discoveries often come out of the blue. Seventeenth century astronomers hoped to be able to use observations of the planets as a way of telling the time anywhere on Earth. They ended up by measuring the speed of light!

In this activity you are going to imagine yourself to be an assistant to the astronomer who made the first good estimate of the speed of light. You're going to be transported back in time to Paris in 1676. You are going to help a Danish astronomer, Ole Roemer, who moved to France in 1672.

The government are pressing astronomers to think up more and more accurate ways of finding the time. They want to be able to set up trade routes across the oceans, and to be successful they need to be able to give their mariners a reliable way of telling the time in Paris. The navigators in the ships can then use the difference between Paris time and their local time to calculate their longitude. Every hour difference in time represents 15^0 difference in longitude from Paris. The best clocks available can keep good time when fastened to a wall in the laboratory, but they are not much use in a ship which is battling through a storm.

You are to record the position of the planets. Ole Roemer is particularly keen to observe the position of Jupiter and its moons over the next few months. He thinks the navigators might be able to use the recently invented telescope to see the moons of Jupiter, and then to use a book of data to work out the time in Paris.

On the first night you look through the best telescope in the observatory and see the moons of Jupiter for the first time. They appear as four bright spots of light in line with the equator of the planet, but they don't seem to be moving. The sketch below shows how the moons, which were discovered by Galileo in 1610, appear through the telescope.

After doing other jobs which take up most of the night, you make another sketch and see that the innermost moon, Io, has moved a little.

Q1. Why might Ole Roemer have suggested that Jupiter and its moons could be used as ' a clock in space'?
Q2. Why does Io appear to have moved a little after a few hours?
Q3. Why does Io appear to move more than the other moons of Jupiter?

The next day, Ole Roemer shows you some work which he has done on the time it takes Io to make one complete orbit round Jupiter. It seems that the period of the orbit of Io is about 42.5 hours. You are set to work recording the orbit of Io as accurately as possible. You record the times on successive nights when Io is eclipsed by Jupiter. When Io passes into the shadow of Jupiter it disappears from view quite suddenly, and so you are able to record the time from the observatory clock in your notebook. You cannot record every eclipse however, because some occur during daylight hours and on some nights the weather is poor.

Q4. Draw a diagram to show the positions of the Sun, Jupiter and Io when Io is eclipsed.
Q5. Would the eclipse of Io always be visible from Earth? Give reasons for your answer.
Q6. Copy and complete the table below and find the mean time for one orbit.

Date	Time of eclipse	Time since last reading	Number of orbits	Time for one orbit in days
15/5/1676	02.09	-	-	-
7/6/1676	02.04	22d 23h 55m*	13	1.76896
23/6/1676	00.11	15d 22h 7m	9	
30/6/1676	02.00	7d 1h 49m	4	

*22d 23h 55m = 22 + 23/24 + 55/1440 = 22.99653d

Mean time for one orbit in days	

The observatory staff are very pleased that you have measured the period of Io so accurately. You now go on to do other work and leave the Jupiter project for the time being.

Nearly half a year later the observatory is not very busy, so Ole Roemer decides it is time to make some more observations of Jupiter. You are sent to get the tables and predict when the next eclipse of Io is due. From a rough calculation you find that about 86 orbits have gone by. You work through the calculations to find which eclipse will be visible, bearing in mind that Jupiter is close to the direction of the Sun and sets only about two hours after it in the evening.

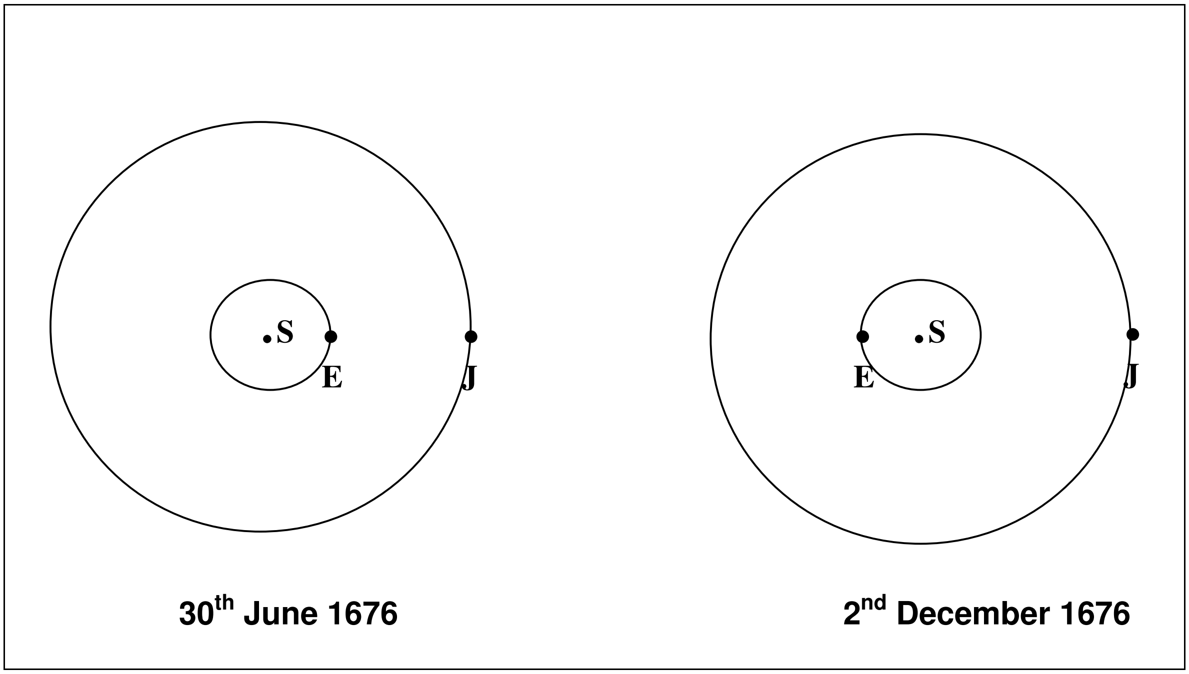
The last eclipse you observed was in the summer on 30th June at 02.00, so using this you draw a new table to predict future eclipses.

Eclipse number	Number x Period of Io (1.769 days)	Time to next eclipse in days and hours	Predicted observation time	Date
86	152.134	152d 3.216h	05.13	29/11/1676
87	153.903	153d 21.672h	23.40	30/11/1676
88				
89				

Q7. Complete the table to show your predictions of the dates and times of the next two eclipses of Io.
Q8. You have to schedule an observing session. Which eclipse will be the most suitable to observe?

When you see the eclipse, you record the time but are worried by the fact that it has happened 20 minutes later than you predicted. You assume that your calculations have an error in them so the next day you check them carefully. No error is found, so you discuss the problem with your fellow astronomers. You take further readings during the next week, but all the eclipses are 20 minutes later than your predictions, even though the period is the same as six months ago. Then, you sense a discovery may be in reach! Perhaps the time difference is not due to an error, but to the fact that the Earth was much nearer six months ago. Perhaps the light takes time to travel from Jupiter to the Earth.

Q9. Study the diagrams below which show the positions of the Earth and Jupiter in their orbits about the Sun at the times of your observations of Io. How have they moved in the intervening time?
Q10. How might this help to explain the fact that your observations of the eclipses of Io in November and December do not occur at exactly your predicted times?
Q11. Using a measure of the diameter of the Earth's orbit about the Sun from the diagrams below, find the difference in the distances travelled by light from Jupiter to the Earth on the two dates in question (you will need to use the scale 1mm: 20 million km).
Q12. Knowing that the difference between observed and predicted eclipse times is 20 minutes, calculate a value for the speed of light.
(Speed in m/s = distance in m / time in s)



Excited by your discovery, you write up your results and pass copies to fellow scientists. Ole Roemer and you are disappointed that philosophers in Paris do not support you – they still believe that light takes no time to pass from one point to another. Much to your relief, you later learn that the English physicist Issac Newton and the Dutch astronomer Christiaan Huygens do support your findings.

POSTSCRIPT

In 1729, James Bradley published results from a rather different experiment using starlight which confirm your work. In 1849, Armand Fizeau, a wealthy French physicist, used a rotating disc to send pulses of light from his father's home in Suresnes to a hilltop some 8km distant in Montmartre, Paris. He managed to time their flight there and back as 50ms. His calculation for the speed of light as 3.12 x 10^8 m/s is quite close to today's accepted value of 3.00 x 10^8 m/s.

Q13. The modern value for the time delay difference from Jupiter is 16.6 minutes. The radius of the Earth's orbit about the Sun is 149.6 million km. Use these values to calculate a value for the speed of light.
Q14. What problems did Roemer and his assistant have which caused their results to lack modern accuracy?