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# Catch the Sun in a Jam Jar

The midday sun in summer is very powerful. Can you say how powerful?

This experiment is simple enough to be done at home.

The idea is to put a jam jar in strong sunlight and measure how quickly its temperature rises. From this you can work out the power of the sunlight.

## Apparatus

* jam jar
* ink (blue or black)
* weighing device
* thermometer (digital is best but any household device will do)
* ruler
* clock or watch

## Part One - Temperature Measurements

Aim: To find rate of rise of the temperature of the jar and water.

* Take the empty jam jar and fill it with water from a tap.
* Adjust its temperature until it is about 2 °C below the surroundings.
* Add several drops of ink until the water is so dark that you can't see through it.
* Stand the jam jar in full sunlight.
* Take a temperature reading.
* Stir occasionally.
* Take temperature readings at 5 minute intervals until the temperature is about 2 °C above the surroundings.
* Work out the average number of degrees the temperature rises each minute.
* (You could plot a graph of temperature against time and find its gradient.)

## Part Two - Area Measurements

Aim: To find the area of sunlight that the jam jar has been absorbing.

* Hold the jam jar in the sunlight with one hand and hold a piece of paper behind it with the other.
* Angle the paper until the shadow is the smallest you can make it.
* With the help of a friend or by remembering where the edges of the shadow fall, mark out its area.

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* Measure the length and breadth of the shadow in millimetres.
* Calculate its area in square millimetres.

## Part Three - Weight Measurements

Aim:  To find the weight of the jam jar and of the water in it.

* Weigh the jam jar when it is empty and again when it is full of water.
* If you use a domestic scale you may need to convert the readings from ounces to grams.  In one ounce there are 28.3 grams.
* Record the weight of the jam jar and the weight of the water.

## Calculations

Power of the Sun in watts per square metre =

$$\frac{\left(\text{wt of jar in g} \times 4.18\right) + \left(\text{wt of water in g} \times 0.67\right)}{\text{area in mm}^2 \times 0.000001} \times \frac{\text{temp change per min}}{60}$$

Discussion of your result:

The NIMBUS and NOAA satellites have measured the power of the Sun to be about 1370 watts per square metre.  At ground level the value is about 1000 watts per square metre.  Why is the ground level result so much lower?

Your result is probably going to be lower than 1000 watts per square metre.  Make a list of the main reasons for this.  Plan how you might alter your experiment to give a more accurate result.

## Questions:

Does the time of day make any difference to the result?  Is there a best time to do the experiment?

Would the result be higher or lower if you could see through the inky water?  Suggest a practical way of proving your answer.

When the jam jar is above or below the temperature of its surroundings it will gain or lose some heat.  Why did the instructions say to start about $2\,°C$ below and continue to about $2\,°C$ above the surrounding temperature?

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## Notes for Teachers:

The Solar Irradiance (Solar Constant) above the atmosphere is about 1370 W/m$^2$ (see http://web.noaa.gov/stp/solar/irradiance). At the surface of the Earth the 'clear sky at noon' value is about 1000 W/m$^2$.

When the jam jar is placed in the sunlight it absorbs heat and light energy and its temperature starts to rise. The ink ensures that no rays pass through the jam jar. In the first ten minutes the jam jar's temperature will rise by about four degrees Celsius so the gains and losses will be quite small (the rate of loss is approximately proportional to the temperature above the surroundings). By starting the experiment about 2°C below surrounding temperature and continuing until it is about 2°C above, the heat gains and losses are effectively cancelled out.

The trick of adjusting the angle of a paper behind the jam jar for the smallest shadow is the simplest way of finding the projected area of the jam jar perpendicular to the Sun's rays. It avoids the need for trigonometry.

The calculation involves finding the energy needed to raise the temperature of the water and the glass. By using the rate of change of temperature, the power input is arrived at directly.

My test experiment was carried out in July. The data were:

Mass of water = 354 g

Mass of jam jar = 227 g

Specific heat capacity of water = 4.18 J/g°C

Specific heat capacity of glass = 0.67 J/g°C

Rate of change of temperature = 0.36 degrees per minute

Area of smallest shadow = 167 × 70 = 11690 mm$^2$

Power of the Sun in watts per square metre =

$$\frac{(354 \times 4.18) + (227 \times 0.67)}{11690 \times 0.000001} \times \frac{0.36}{60} = 837 \,\text{W/m}^2$$

Lack of perfect absorption and loss to the surroundings all contribute to the reduction of the value from 1000 W/m$^2$. Your experiment might well give an even lower value!!

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If you have access to a Lees' Disc apparatus, you can use the large copper disc for this experiment. Blacken on side with soot from a flame or with a thin layer of paint. Set the disc perpendicular to the Sun's rays and take a series of temperature readings.

You can do the simple experiment described above or you can follow the Lees' Disc method of allowing the temperature to stabilise and then to shadow the disc and measure the rate of fall of temperature. Judge the rate at the equilibrium temperature from a tangent drawn on the graph.

The jam jar experiment is simple to perform and can easily be done at home. It raises questions about the atmosphere and about the Sun. The graph on the NOAA web site shows that the Sun's output is not constant, varying by about 2 $W/m^2$ over a period of 11 years. The variation is linked to the Sunspot cycle, being greater at times of maximum Sunspot activity.

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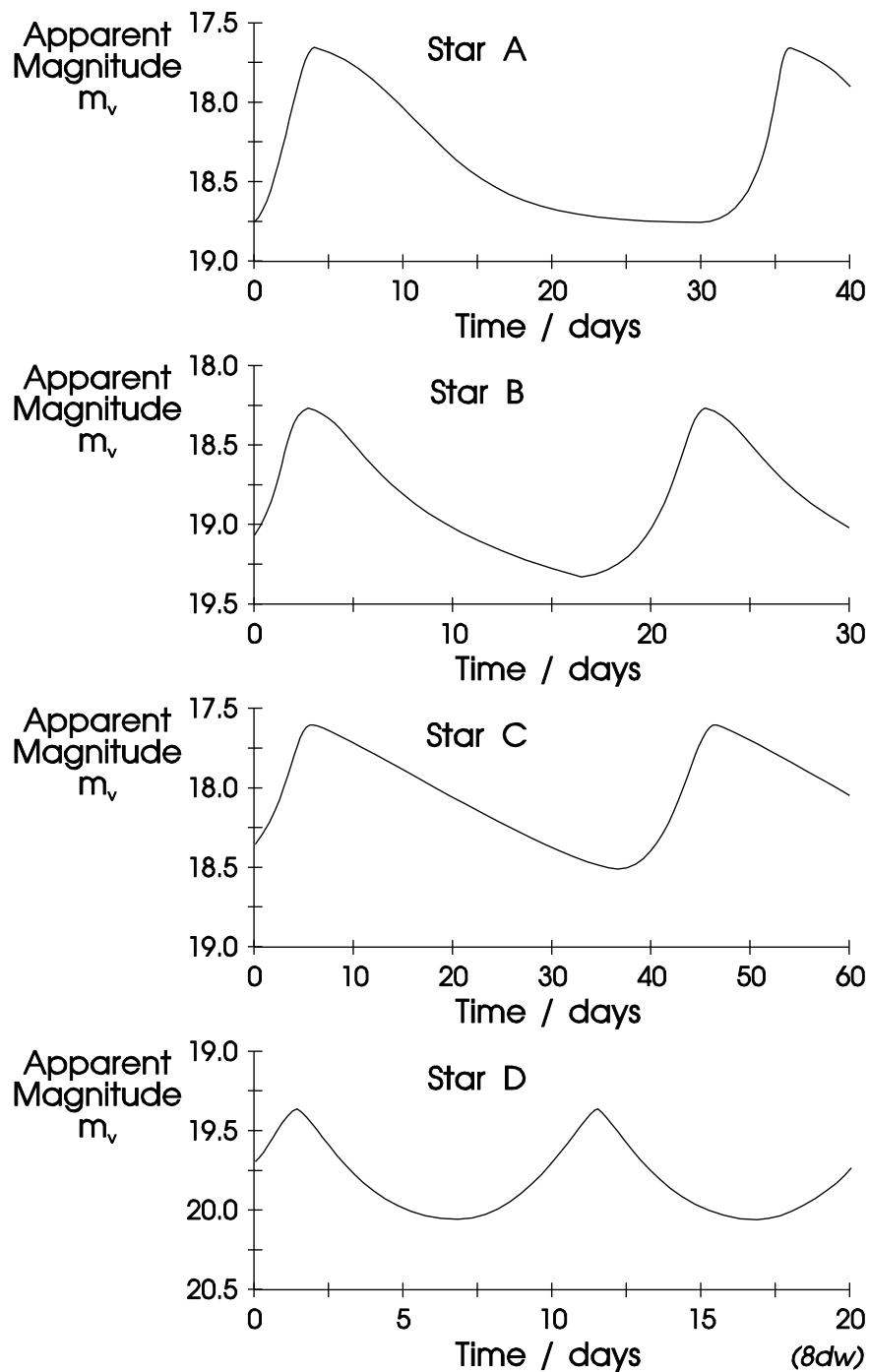
## Cepheid Worksheet

To find the distance to galaxies is not easy because they are too far away to show any parallax. The most direct methods involve 'standard candles'. We can measure the distance to a nearby star and also measure its magnitude. If we can then observe a similar star in a distant galaxy we can then compare the stars' magnitudes and so find the distance to the galaxy.

## Light Curves of Cepheid Variable Stars in the Andromeda Galaxy



Apparent Magnitude $m_v$ — Star A — Time / days



Apparent Magnitude $m_v$ — Star B — Time / days



Apparent Magnitude $m_v$ — Star C — Time / days



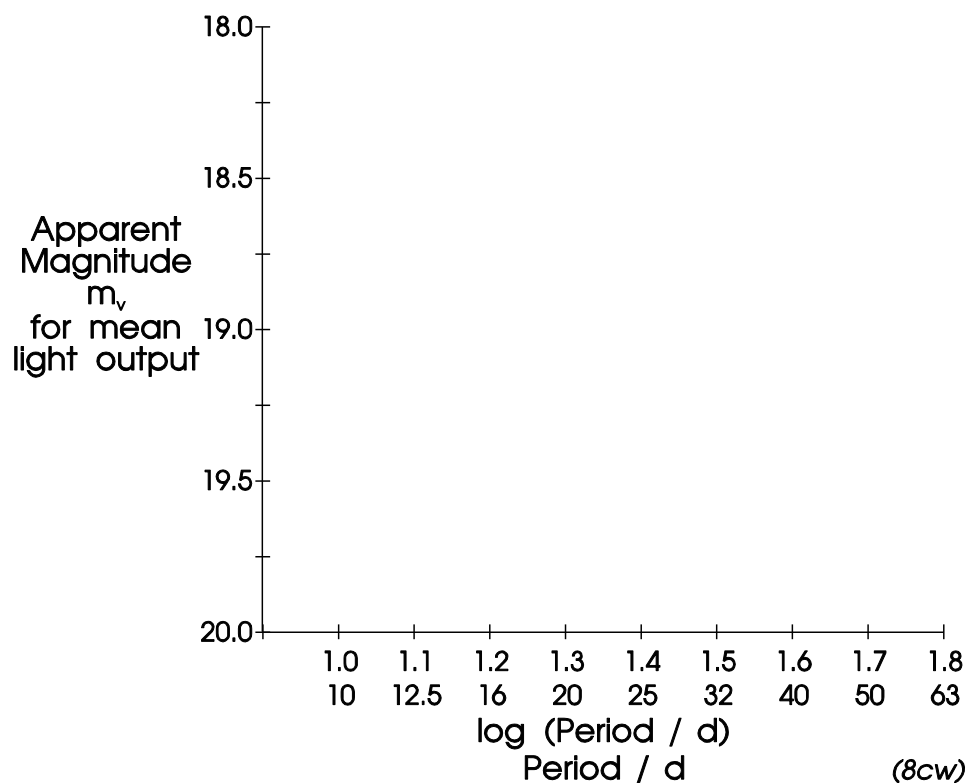Apparent Magnitude $m_v$ — Star D — Time / days

*(8dw)*

## Verification of the Period-Luminosity Law

In 1912 Henrietta Swan Leavitt, working at Harvard, found that Cepheid variable stars could be used as standard candles. The four light curves are for Cepheids in M31, the Andromeda galaxy. From the curves find:

* The period of the variability and
* The average apparent magnitude of the star.

Complete the table and plot the results on the graph.

| Star | Apparent Magnitude | Period / days |
|------|--------------------|---------------|
| A    |                    |               |
| B    |                    |               |
| C    |                    |               |
| D    |                    |               |

Apparent Magnitude $m_v$ for mean light output

| | 1.0 | 1.1 | 1.2 | 1.3 | 1.4 | 1.5 | 1.6 | 1.7 | 1.8 |
|---|---|---|---|---|---|---|---|---|---|
| | 10 | 12.5 | 16 | 20 | 25 | 32 | 40 | 50 | 63 |

log (Period / d)
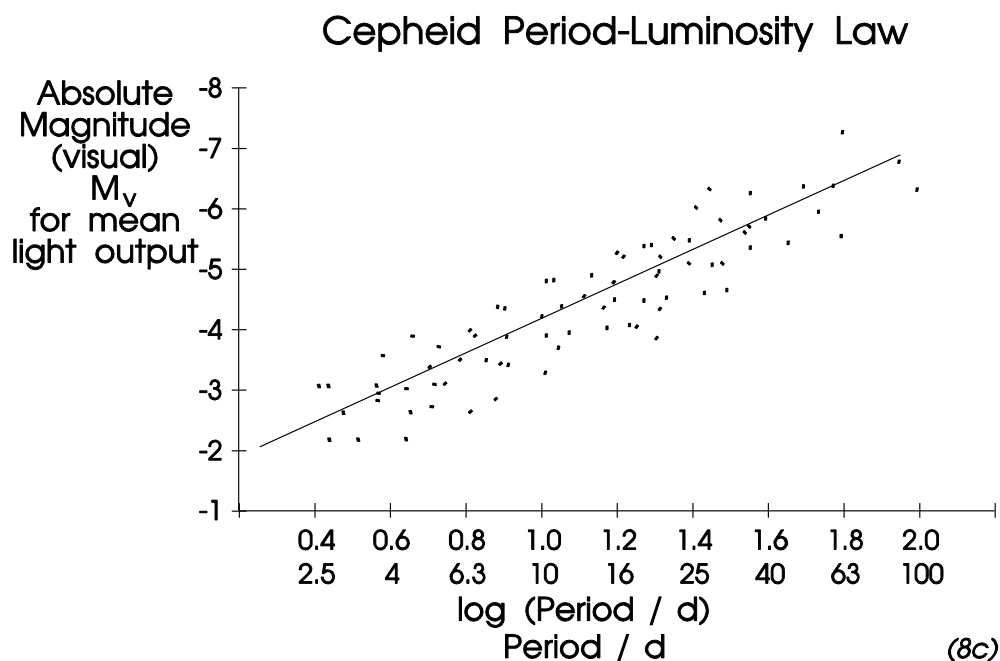Period / d                    *(8cw)*

Henrietta Swan Leavitt plotted similar graphs and realised that the mean apparent magnitudes of the stars were proportional to the logarithms of their periods. This was a major step forward. A year later, in 1913, Harlow Shapley was able to measure directly the distance to a few nearby Cepheids and so was able to link their absolute magnitudes to their periods. The standard candles had been found! This lead to the final proof that the galaxies were outside our own Milky Way and that the scale of the Universe was truly massive.

## Distance to Andromeda

The graph shows the modern results for Cepheid Variables. You can use the data to estimate the distance to the Andromeda galaxy. Try using the data for Star C. Look up the absolute magnitude of a star of the same period as Star C. Substitute your results into the formula below. Be careful with the signs of the magnitudes!

### Cepheid Period-Luminosity Law



Absolute Magnitude (visual) $M_v$ for mean light output

log (Period / d)

Period / d

*(8c)*

$$m - M = 5\log\frac{d}{10}$$   where   m is the apparent magnitude,

M is the absolute magnitude and
$d$ is the distance in parsecs.

This formula should give a value for the distance to the Andromeda galaxy of about two million light years. There are 3.26 light years in a parsec.

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# Eratosthenes' Method to Measure the Circumference of the Earth

Eratosthenes of Cyrene (275 - 194 BC) was a Greek mathematician and astronomer and was head of the library at Alexandria at the end of the third century BC. He noted that whilst the Sun was directly overhead in Syene (Aswan) at noon on the Summer Solstice, it was not quite overhead in Alexandria on the same day. From this he deduced that the Earth must be curved. Furthermore, with the aid of a traveller who had walked between the two cities and had estimated the distance between them, Eratosthenes calculated the circumference of the Earth. His value of 46 000 km was quite close to the present day value of 40 075 km.

## A Simple Model

The calculation relies on simple trigonometry. Imagine two observers, one on the equator and one due North at latitude 30°. They both observe the angle of the Sun from the zenith (overhead).

On a day when the Sun is overhead on the equator the first observer would report the angle as 0° and the second as 30°. Now imagine (and this requires some considerable imagination!) that the observer at 30° walks directly to the one on the equator and measures the overland distance accurately.

To find the circumference of the Earth, all that is required is to multiply the distance by twelve $(360/30)$.

## A Reconstruction of the Original Experiment

A modern map gives the distance between Aswan and Alexandria as 817 km. Their latitudes and longitudes are:

|  | Latitude | Longitude |
|---|---|---|
| Syene (Aswan) | 24.0° | 32.9° |
| Alexandria | 31.2° | 29.8° |

As far as we know, Eratosthenes assumed that the two cities had the same longitude. However the method below shows how to do a precise calculation.

To proceed, you need to use a formula from spherical trigonometry. This is not as bad as it sounds!!

The formula links the length of the arc joining two points to their latitude and longitude:

$$\cos\theta = \cos(90 - \text{latitude S}) \times \cos(90 - \text{latitude A})$$
$$+ (\sin(90 - \text{latitude S}) \times \sin(90 - \text{latitude A})$$
$$\times \cos(\text{longitude S} - \text{longitude A}))$$

The angle q is the angle between the lines joining the two points, A and S, to the centre of the Earth. This theory assumes that both points are in the Northern Hemisphere and that the longitude difference is positive, as it is.



's' is the walking distance between the cities

Looking at the two cities

*(Erat3)*
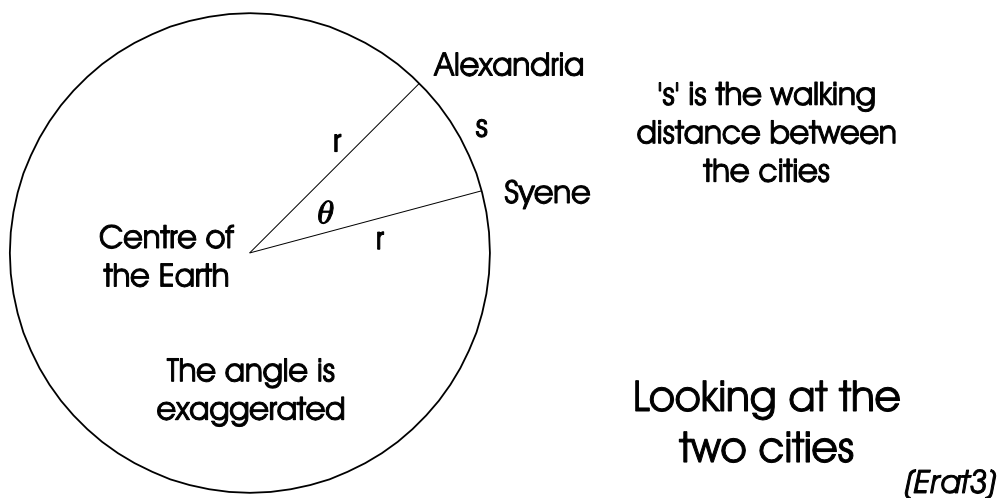
The arc length *s* is calculated using:

$$s = r \times \theta \qquad \text{where } \theta \text{ is measured in radians and}$$
$$r \text{ is the radius of the Earth.}$$

This arc length is the walking distance between Alexandria and Syene.

The latitude, longitude and walking distance can then be used to calculate the radius and circumference of the Earth.

$$\cos\theta = \cos(90 - 24.0) \times \cos(90 - 31.2)$$
$$+ \sin(90 - 24.0) \times \sin(90 - 31.2) \times \cos(32.9 - 29.8)$$
$$= \cos(66.0) \times \cos(58.8)$$
$$+ \sin(66.0) \times \sin(58.8) \times \cos(3.1)$$
$$= 0.99097$$
$$\therefore \theta = 7.705\,°$$

Substituting the walking distance s:

$$r = \frac{s}{\text{angle } \theta \text{ in radians}}$$

$$= \frac{817}{\dfrac{\pi \times 7.705}{180}}$$

$$= 6075 \, \text{km}$$

If you want to repeat this calculation, be careful to convert the angle $\theta$ to radians.

The equivalent circumference is $38\,200$ km.

Can you see what assumptions have been made in this theory?

Two references which devote a page or two to this subject are:

Greek Science after Aristotle        G E R Lloyd        Norton
                                    0-393-00780-4

        £6.95

The Hellenistic World        F W Walbank        Fontana
                                    0-00-686104-0

        £8.99

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## A Modern Experiment

Two observers find their latitudes by measuring the lengths of shadows cast at the time of their local noon on the same day. The north-south distance between the sites is then measured from a map. (Here is a problem, since the map has been made *using* a value for the radius of the Earth. Oh well, you could *imagine* walking the distance!!)

## Theory

This method means that the longitude difference is zero and so the formula becomes:

$$r = \frac{\text{north - south map distance}}{\frac{\pi \times \text{latitude difference in degrees}}{180}}$$

The $\frac{\pi}{180}$ factor converts from degrees to radians.

Recent pupil data from Manchester and Athens gives a latitude difference of 13.5º and a north-south walking distance of 1 710 km. This gives a radius of 7 260 km. Using the map latitude difference of 15.4º, this becomes 6 360 km. It shows how hard it is to take accurate shadow measurements!

Using a map derived city-to-city walking distance of 2613 km and the latitude and longitude of Manchester (53.45ºN, 2.22ºW) and Athens (38.05ºN, 23.86ºE), the full formula gives a radius of 6 340 km!

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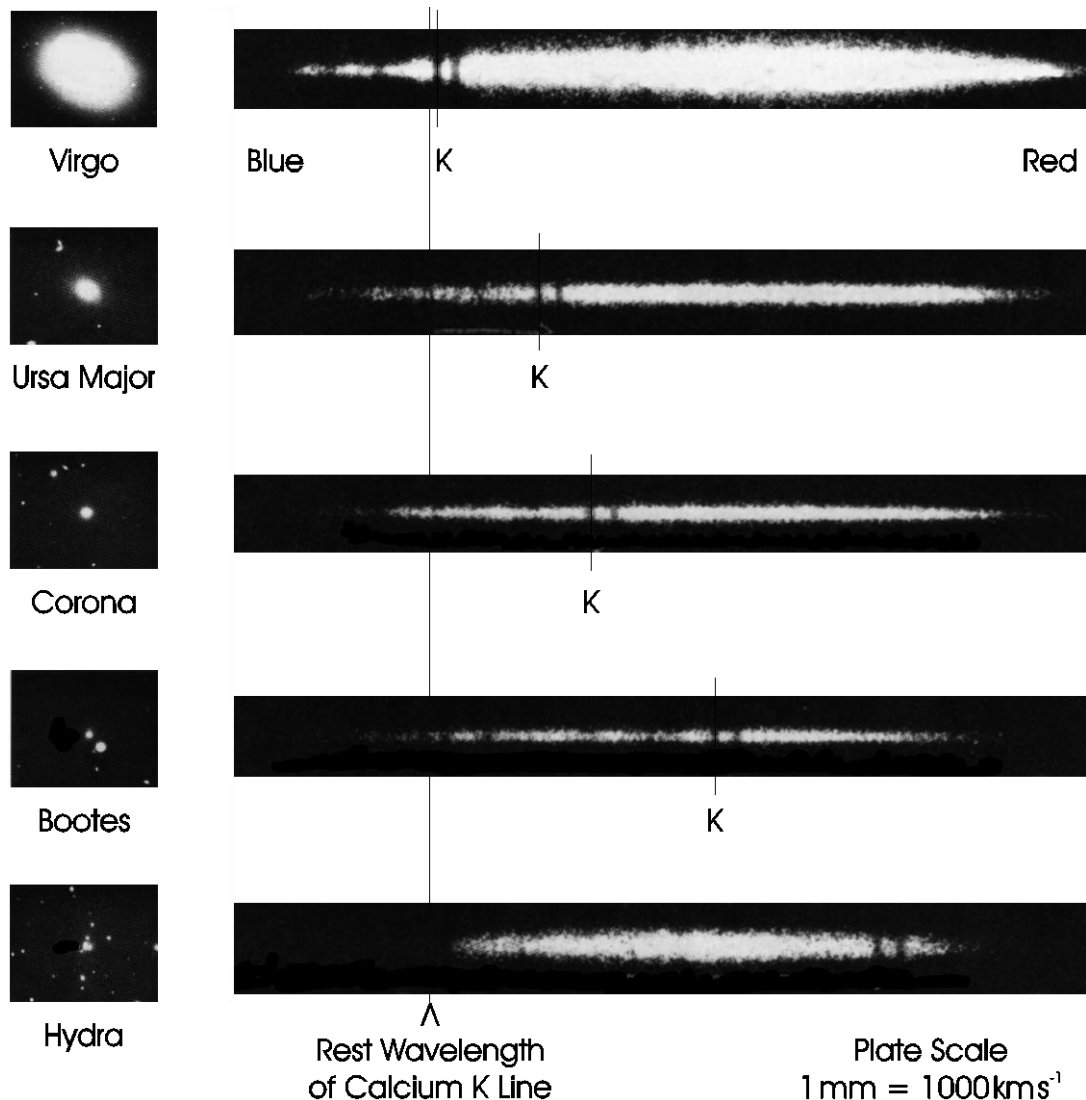
## Hubble Worksheet

The light from galaxies is very faint. With the naked eye we can only see one (Andromeda) in the Northern sky. To make a photograph of the spectrum of a galaxy requires a large telescope to collect the light. By the 1920s, spectra similar to the ones below had been collected. Work then progressed on finding the distance to the galaxies. Various methods were used and by 1929, Edwin Hubble had measured the distances to about twenty galaxies. With this information he was able to show a definite link between the distance to a galaxy and the speed it is moving away from us.

In the exercise, you are provided with five spectra adapted from Hale Observatory originals. A spectral line of Calcium is marked. If the galaxy is stationary relative to us, the Calcium K-line is observed at its rest wavelength. If the galaxy is receding, the wavelength becomes longer - the Doppler Effect.



| Virgo | Blue | K | Red |

Ursa Major    K

Corona    K

Bootes    K

Hydra

∧
Rest Wavelength
of Calcium K Line

Plate Scale
1mm = 1000kms$^{-1}$

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In the table, four of the galaxies have their distances given. Use the 'plate scale' on the diagram to find the recession velocities of the galaxies. You will have to judge the position of the K-line in the Hydra spectrum yourself.

* Fill in the table and plot the graph of recession velocity against distance.
* Use the graph to find the distance to the galaxy in Hydra.
* Find the gradient of the graph - it is the value of the Hubble Constant.

| Galaxy | Velocity / km s$^{-1}$ | Distance / Mpc |
|---|---|---|
| Virgo | | 16 |
| Ursa Major | | 200 |
| Corona | | 293 |
| Bootes | | 520 |
| Hydra | | |

Recession Velocity / km s$^{-1}$

(graph with y-axis marked 0, 10000, 20000, 30000, 40000, 50000, 60000, 70000 and x-axis marked 0, 200, 400, 600, 800)

Distance / Mpc          *(9aw)*
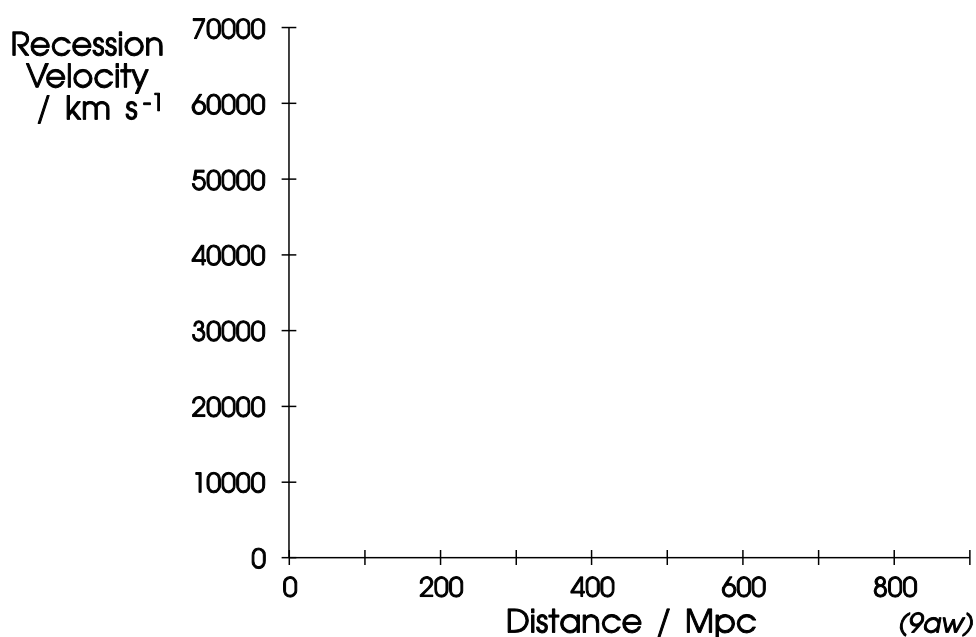
Modern spectra are very, very much better than these! It is instructive to see the difficulties that early workers in this field overcame.

# Resolution of the Eye Worksheet

The resolution of the eye is limited by three main factors:

* Aberrations in the cornea and lens system,
* The spacing of the light-sensitive cells in the retina and
* The diffraction pattern produced at the retina when light passes through the iris.

In this exercise you are to compare the various angles that can be obtained from given data and from your own visual measurements.

## Data

* Spacing of the rods and cones in your retina is about $2.5 \times 10^{-6}$ m
* Diameter of your eyeball is about $1.7 \times 10^{-2}$ m
* Wavelength of yellow light is about $5.8 \times 10^{-7}$ m

## Experiments

Find a dark corner of the room and measure the diameter of your pupil using a mirror or with the help of a fellow experimenter. Go to a bright part of the room and repeat the measurement.

Place cross 'A' against a vertical surface and walk away from it until you just cannot make out the individual lines. Measure your distance from the cross and also measure the spacing of the individual lines.

Collect your results and compare the four angles generated by dividing the data pairs. All four results in some way represent, in radians, the smallest angular separation of objects that your eye can resolve.

$$\text{Ratio} = \frac{\text{Spacing of cells in retina}}{\text{Diameter of eyeball}} = \cdots\cdots\cdots\cdots\cdots = \underline{\qquad}.$$

$$\text{Ratio} = \frac{\text{Wavelength of yellow light}}{\text{Smaller diameter of pupil}} = \cdots\cdots\cdots\cdots\cdots = \underline{\qquad}.$$

$$\text{Ratio} = \frac{\text{Wavelength of yellow light}}{\text{Larger diameter of pupil}} = \cdots\cdots\cdots\cdots\cdots = \underline{\qquad}.$$

$$\text{Ratio} = \frac{\text{Spacing of lines in cross}}{\text{Distance from eye to cross}} = \cdots\cdots\cdots\cdots\cdots = \underline{\qquad}.$$

_____

## Commentary

Your eye can only see two objects as distinct if there is at least one 'dark' rod or cone between their images. This means that the resolution estimated by the first formula is too great.

The aberrations in the eye's lens system make a considerable difference to the clarity of focus of an image. If the pupil is small, you might think that the diffraction spread would be more of a problem but this is not necessarily so. Try observing the test cross in brightly illuminated conditions and then with the cross brightly illuminated but with yourself in a dark corner.

The important point of this experiment is to combine having fun with comparing some rather difficult to interpret data.

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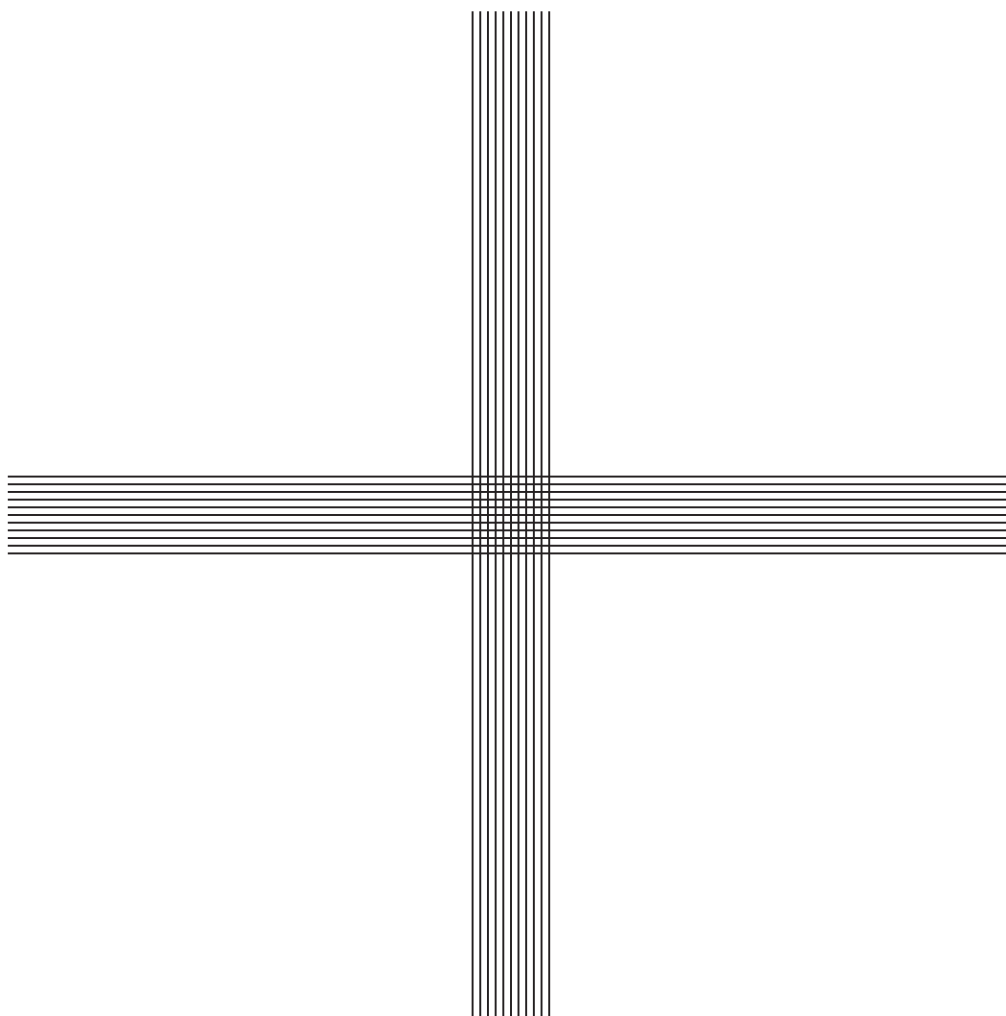
Cross A

Rømer Worksheet

# The First Measurement of the Speed of Light

## Introduction

The first measurement of the speed of light was made by Ole Rømer (Roemer) in 1676. He used predictions of the orbits of the moons of Jupiter to calculate the time of flight of light across the space between Jupiter and the Earth.

The Greek view was that of instantaneous action. Aristotle certainly held the view that light travelled at infinite speed. In 300 BC Euclid was writing about geometry and his contemporaries wrote about straight line propagation of light, the laws of reflection and had observed refraction (although the sine law was not discovered until 1621). The Islamic scientist Avicenna (980 - 1037) reasoned that the speed must be very fast but not infinite. Galileo Galilei suggested an experiment with two lamps on hilltops several kilometres apart. Shutters would be used to flash a signal to the far hill from where it would be returned. This was tried in Florence but the time of flight of the signal was too short to measure.

Roemer was attempting to improve predictions of the orbits of the four bright moons of Jupiter; Io, Europa, Ganymede and Callisto. When he took readings of the eclipse time of Io in successive months he found that the observed time drifted earlier as the distance between the Earth and Jupiter decreased and then drifted later as the distance increased. The time difference was 22 minutes between the extremes. This allowed him to calculate the speed of light using his knowledge of the orbits of the planets.

## Imagine your are the assistant to Ole Rømer

The journey you are about to go on may seem rather fanciful but any keen student could repeat the work we are going to do using only a pair of binoculars and a watch.

You are about to become an assistant to the astronomer who first measured the speed of light. Imaging yourself transported back in time and space to Paris in 1676. You are to help a Danish astronomer, Ole Rømer, who moved to France only four years previously.

The government is pressing the 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 calculate their longitude. Every hour difference in time represents fifteen degrees difference in longitude from Paris. The best clocks available can keep good time when fastened to a wall in the laboratory but are not much use in ship which is battling through a storm.

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

On the first night you are allowed to look through the best telescope in the observatory and you see the moons of Jupiter for the first time. They appear as four bright pinpoints 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.



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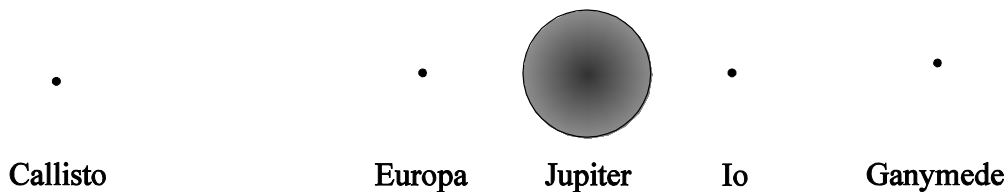
After doing other jobs which take most of the night you make another sketch and you see that the innermost moon, Io, has moved a little.

The next day Ole Rømer 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 Io is about one day and eighteen and a half 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 master clock in your notebook. You can't record every eclipse because some occur during the daylight hours and on some nights the weather is poor.

Your notebook looks like this; finish off the calculations for one orbit and find the average time:

| 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 | |

| Average Time | |
|---|---|
| | |

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 has gone by and the observatory is not very busy so Ole Rømer decides it is time to make some more observations of Jupiter. You are sent to get the previous tables and to work out 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.

| Eclipse Number | Number × 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 | |
| 87 | 153.903 | 153d 21.672h | | 1/12/1676 |
| 88 | 155.672 | 155d 16.128h | | 3/12/1676 |
| 89 | 157.441 | 157d 10.584h | 12:35 | |

You complete the table and are able 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 to be found so you discuss the problem with your fellow astronomers. What could be wrong?

You take further readings during the next week but all the eclipses are 20 minutes later than your predictions even thought the period is the same as six months ago. Then you sense a great discovery might be within reach. Perhaps the time difference is not due to an error but to the fact that the Earth is much nearer Jupiter than it was six months ago. Perhaps the light takes time to travel from Jupiter to the Earth. You consult a chart of positions of the planets and make the simple diagram overleaf:

Using the scale you read off the distance between the Earth and Jupiter.

**30 June 1676**

Sun
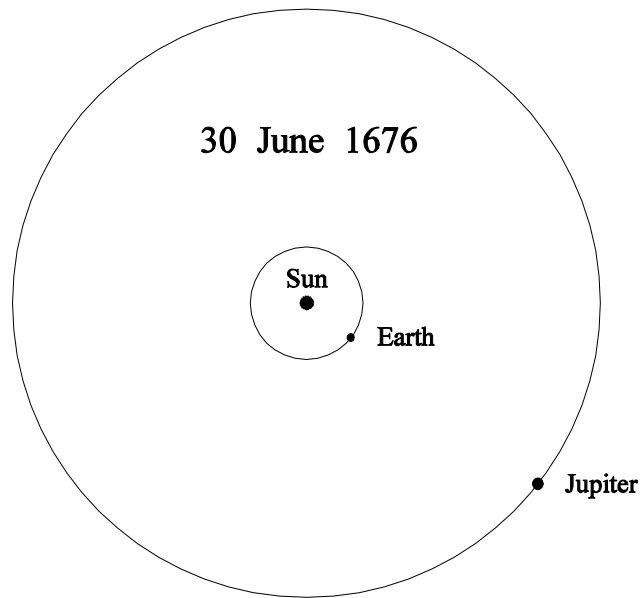
Earth

Jupiter

```
0    200   400   600   800  1000
     Millions  of  kilometre
```

**1 December 1676**

Earth

Sun

Jupiter

_____
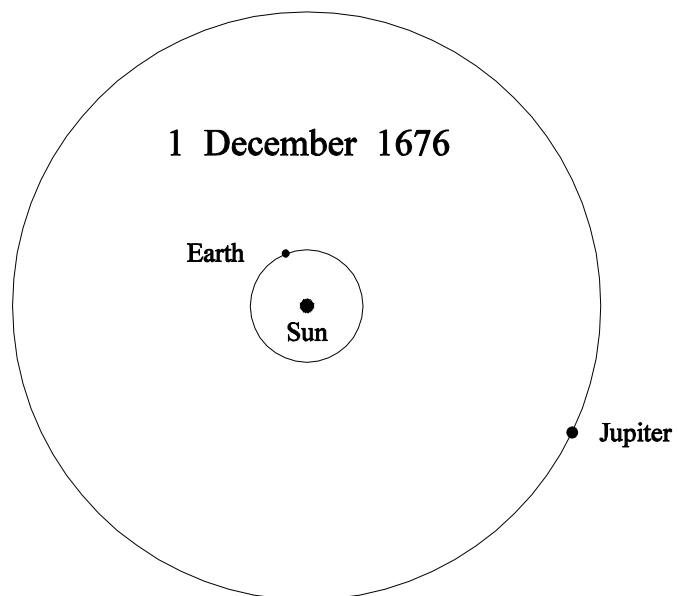
| Date of Reading | Scale Length of Path from Jupiter to Earth | Length of Path converted to metres using the scale |
|---|---|---|
| 30/6/1676 | | |
| 1/12/1676 | | |

| | Difference in Path Length | |
|---|---|---|

Knowing that the time difference is 20 minutes you then go on to calculate the speed of light.

Speed of Light = Distance in metres / Time in seconds =           m/s.

Excited by your discovery you write up your results and pass copies to your fellow scientists.  How disappointed you and Ole Roemer are to find that the philosophers in Paris do not support you.  They still hold that light travels from one point to another with no time delay at all.  Much to your relief you later learn that Isaac Newton and the well known Dutch astronomer Christiaan Huygens do support your findings.

## Postscript

In 1729 James Bradley published results from a rather different experiment using the direction of arrival of 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 eight kilometre distant in Montmartre, Paris.  He managed to time their flight there and back;  only 50 microseconds.  His result of

312 000 000 m/s was close to the accepted value of 300 000 000 m/s.

The modern value for the maximum time delay difference from Jupiter is 16 minutes and 36 seconds.

What might have caused your results to lack the modern accuracy?

## Extension

It is quite easy to see the moons of Jupiter with a pair of binoculars and the fine bright pinpoints of the Galilean moons, shining in the reflected sunlight, are a remarkable sight. It would be perfectly possible to repeat this experiment on a month by month basis. A computer program such as Redshift can show the positions of the planets which would allow the distances from Earth to Jupiter to be obtained.

# Royal Observatory Edinburgh
# Schmidt Survey Plates

## Identification Exercise

VIRGO

| | |
|---|---|
| A | |
| B | |
| C | |
| D | |
| E | |
| ? | |

PLATE 276

| | |
|---|---|
| A | |
| B | |
| C | |
| D | |
| E | |
| ? | |

# Spectra of Floodlights Worksheet

There are at least six types of lamp used for lighting today. In this exercise you are to compare the various wavelength of light emitted from the light fittings and use the table of known wavelengths to identify the atoms present. The spectra merit careful inspection as they show not only spectral lines but also bands. In one case the familiar yellow lines of sodium have completely disappeared!

## Procedure

Direct the spectrometer at a normal fluorescent lamp and find the bright green spectral line that is just short of 550 nm. Check that it lines up with the small calibration mark in the lower part of the scale. If it does not, seek help.

Direct the spectrometer at each of the light sources in turn and record the wavelengths of a few of the brighter lines.

Look over your results and see if you can see any patterns in the data.

## Results and Data Table

| Lamps | | | | | Elements | | | | |
|---|---|---|---|---|---|---|---|---|---|
| A | B | C | D | E | Na | Hg | I | Br | W |
| | | | | | | 365 | | | |
| | | | | | | 366 | | | |
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| | | | | | | 546 | 546 | | |
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| | | | | | | 577 | | | |
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| | | | | | 615 | | | | |
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## Commentary

This experiment shows how hard it is to identify elements from data of modest precision!  Astronomers trying to find the redshifts of galaxies in the 1920s probably had to work with poorer spectra than the ones you have seen here.  When the light from a distant galaxy is spread out into a spectrum, the image is very faint.  The images were recorded on photographic plates but were poor, even if the light was integrated for many hours by tracking the source round the sky.

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## Answers

| SON | MB-FU | HMI | SOX | CFL | Na | Hg | I | Br | W |
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| | | | | | | 365 | | | |
| | | | | | | 366 | | | |
| | **382** | | | | | | | | |
| | | | | | | | | | 401 |
| | | | | | | | | | 429 |
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| | | | | 432 | | | | | |
| | 436 | 436 | | 436 | | 436 | | | |
| | | 438 | | | | | | | |
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| 467 | | | | | | | | | |
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| | | 474 | | | | | | | |
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| | **497** | | | | | | | | |
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| | | 510 | | | | | | | |
| 516 | | | 516 | | | | 516 | | |
| | | 521 | | | | | | | |
| | | | | 532 | | | | | |
| | | 535 | | | | | | | |
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| | 546 | 546 | | | | 546 | 546 | | |
| | | 549 | | 548 | | | | | |
| 552 | | 552 | | | | | | | |
| 569 | | 569 | 569 | | 569 | | | | |
| | 577 | 577 | | | | 577 | | | |
| | 579 | 579 | | | | 579 | | | |
| 589 | | 589 | 589 | | 589 | | | | |
| | **595** | | | | | | | | |
| | | | | 612 | | | | | |
| 615 | **615** | | | | 615 | | | | |
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| | **620** | 620 | | | | | | | |
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| | | 628 | | | | | | | |

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| | | 668 | | | | | | | |
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| | 695 | | | | | | | | |
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| | 701 | | | | | | | | |

It is interesting to note that the HMI lamp, in particular, has several lines that are not listed in this table. Here is a research project!!