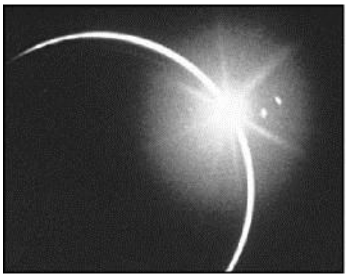
The designer universe?



UNIT 11

In this unit, the Universe provides a context for students to work with numbers expressed in standard form using positive powers of ten. They also consider some of the amazing facts that scientists are discovering about Earth's place within the Universe.

Mathematical content

Number (AT2)
- **Rounding numbers to a given number of significant figures**
- **Standard form (with positive powers of ten only)**
- **Multiplying of powers of numbers**

Shape and Space (AT3)
- **Scale drawing**

Using this unit

The unit is intended for students at the Intermediate/Higher Tier of GCSE. The focus of the work is on numbers written in standard form, but only positive powers of 10 are used. There is only a brief note on standard form in the text, so students will need to have been taught how to write numbers greater then ten in standard form before they attempt the unit. (Negative powers are addressed in the unit, "The Inside Story".) It is expected that the unit will last for about 2 to $2^1/_2$ hours.

The unit has several sections, each looking at different aspects of the Universe and offering an interesting context within which standard form can be practised. There is also opportunity for discussion about our place in the Universe and reflection on issues related to the Anthropic Principle. Students are asked to consider different points of view and make up their own minds.

There is an extension activity at the end for more able students.

Spiritual and moral development

The unit aims to promote a sense of wonder about the Universe and also to encourage students to reflect on the possibility of the Universe being designed.

Students will need A3 paper (task 3, question 3), a calculator, compasses and a ruler.

Background

In recent years, there has been a growth of interest in popular science writing. Some of these books report how scientists, who have studied the place of Earth in the Universe, have been amazed and challenged by the precision and balance they have found. There appear to be so many variables that are "just right" for the production of the conditions necessary for life on Earth. This has led many to conclude that the Universe was designed in order to produce such life. This is known as the 'Strong Anthropic Principle'. Some scientists respond to this purposeful design by searching for a loving, creator God. Others, Stephen Hawking amongst them, will only subscribe to a weaker form of the principle and argue that, if conditions were not suitable for life, we would not be here discussing them!

Additional sources

Books:
P. C. W. Davies, *The Accidental Universe* (Cambridge University Press, 1982).
John Polkinghorne, *Quarks, Chaos and Christianity* (Triangle, 1994).
Felix Pirani and Christine Roche, *The Universe for Beginners* (Icon Books Ltd., 1993).
Michael Poole, *A Guide to Science and Belief* (Lion, 1994).
Christopher Maynard, *Stars and Planets* in the Usborne Young Scientist Series (Usborne, 1991).
Philip & Phylis Morrison, *Powers of Ten* from the office of Charles and Ray Eames (Scientific American Library, 1982).
Further Science from the "Science at Work" series (Longman, 1993).
David Wilkinson, *God, the big bang and Stephen Hawking* (Monarch, 1993).

Video:
"Powers of Ten" the film, produced by the office of Charles and Ray Eames. Available on video cassette (ISBN 0-7167-5029-5) from Marketing Dept., W. H. Freeman and Company, 41 Madison Avenue, New York, NY 10010.

Internet:
Internet pictures from the Hubble telescope at http://www.seds.org/hst/hst.html

Notes on the activities

The unit requires an introductory activity in order to start students thinking about their place in the Universe. Task 1 could be used for this purpose. However there are alternative resources suggested in the additional sources section. The video or the book *Powers of Ten* would be a powerful introduction, as would a selection of pictures from the Hubble telescope. Some students may belong to an astronomy club and could be asked to give a short presentation.

Earth and its moon

The students are given a definition of standard form in the text, but it is important that students have been introduced to writing numbers in standard form. They also need to know how to round numbers to a given number of significant figures before beginning this section.

Our solar system

Question 3 within task 3 is a drawing exercise, so equipment and paper is needed at this stage.

Class discussion

This section leads students into considering the two sides of the Anthropic Principle argument and is an opportunity for a class debate. It is important, therefore, that when planning lessons, time for class/group discussion is included. The issues that could be addressed are:

u their understanding of the argument put by Pirani;
u their understanding of the argument put by Polkinghorne;
u their own opinions on the two arguments and their own reactions to the conditions for life being "just right".

Students could be asked to prepare short talks supporting one side of the argument or the other.

The Milky Way

This section requires students to multiply numbers given in standard form, for which they may need support. Before this section, scientific calculators are not necessary. However, from this stage onwards the students can practise using the standard form function on the calculator. Some students may need support in this.

The Universe

This is the final core section and again leads students into reflecting on the origins of the Universe.

Class discussion

It is recommended that students make a written response to the text. This helps prepare them for a concluding discussion on the ideas raised by the unit. This might address:

u their reactions to the immense size of the Universe;
u whether they think that life came about through amazing chance or through design; u
whether their views on these issues affect the way they live their lives.

Light years away (extension activity)

This activity offers more challenging problems.

Answers

Task 1:

Jo Planet, 15 Nowhere Street, Rotherham, South Yorkshire, England, United Kingdom, The British Isles, Europe, The Northern Hemisphere, Earth, The Solar System, The Milky Way, The Galaxies, The Universe.

Task 2:

1. 1.2756×10^4 km.
2. a) not possible to be so accurate over such a large distance.
   b) 40,100 km.
   c) 4.01×10^4 km.
3. a) 3.476×10^3 km.
   b) 1.09×10^4 km.
4. a) 3.84×10^5 km.
   b) 7.68×10^5 km.

Task 3:

1. Mercury 4.878×10^3; Venus 1.21×10^4; Earth 1.2756×10^4; Mars 6.79×10^3; Jupiter 1.428×10^5; Saturn 1.2×10^5; Uranus 5.24×10^4; Neptune 5.045×10^4; Pluto 2.3×10^3.
2. Pluto; Mercury; Mars; Venus; Earth; Neptune; Uranus; Saturn; Jupiter.
3. Scale drawing.
4. Mercury 57,900,000; Venus 108,000,000; Earth 149,600,000; Mars 227,900,000; Jupiter 778,000,000; Saturn 1,427,000,000; Uranus 2,870,000,000; Neptune 4,497,000,000; Pluto 5,900,000,000.
5. Saturn.
6. Pluto.

Task 5:

1. 2×10^{51} kg.
2. 4.4×10^6 km.
3. 7.6×10^{23} tonnes.
4. 1.1×10^{21} tonnes.
5. 2.5×10^8 years.

Task 6:

1. a) 8.4×10^8 km.
   b) 2.6×10^9 km.
2. 4×10^{51} kg.

Task 7 (Extension):

1. a) 1.8×10^{7} km.
   b) 1.08×10^{9} km.
   c) 2.592×10^{10} km.
   d) 9.4608×10^{12} km.
   e) 9.46×10^{12} km.
2. 2.2×10^{19} km.
3. 3.0×10^{17} km.
4. 1.2×10^{18} km.
5. 2.5×10^{17} km.
6. a) 3.8×10^{8} km.
   b) 7.8×10^{7} km.
   c) 3.6×10^{4} km per hour.
   d) 30 days.
   e) Mars and Earth will move relative to each other during the journey and so the spacecraft will have to travel along a curved path.

TEACHER'S NOTES

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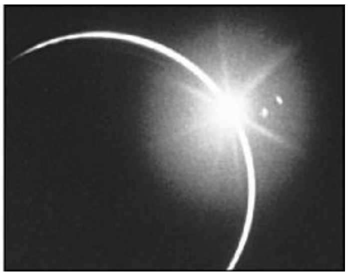

UNIT 11

In this unit you will be working with large numbers written in standard form. The Universe provides us with plenty of examples of very large numbers. But before we get going, let's think about where we are in the Universe.

1

Have you ever sent a letter to someone and tried to make their address as long as possible? Here is a list of some of the places you could use to write to someone called Jo Planet who lives in the town of Rotherham.

The Northern Hemisphere; 15 Nowhere Street; The Solar System; Jo Planet; The Universe; Earth; The British Isles; England; Rotherham; The Galaxies; Europe; United Kingdom; South Yorkshire; The Milky Way.

Write Jo Planet's address in the correct order.

To a cosmologist (someone who studies the Universe) there is nothing remarkable about our Earth.

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It is just a small planet with one moon ...

circling an ordinary star, the Sun.

The Sun is a medium sized star in a galaxy, the Milky Way.

There are thousands of millions of galaxies in the Universe.

But, there is one very extraordinary thing about planet Earth ...
... we live here!!!

info

Distances in space are enormous and so it is best to write any numbers in standard form.

Remember, a standard (or scientific) form number comes in three parts:

A number between 1 and 10
(not including 10 itself)
A multiplication sign
A power of 10
For example 3.67×10^{11}

Earth and its moon

Now let's take a closer look at our amazing Universe.

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2

1. Earth has a diameter of 12,756 km. Write this number in standard form.

2. We can now calculate the distance around the equator by using the formula for the circumference of a circle.

Circumference of the Earth = π x diameter of the Earth
= π x 12756
= 40,074.15589 km

This is the answer you might get on your calculator but it is not sensible to give the answer to this degree of accuracy.

a) Write a sentence explaining why it is sensible to round off this number.
b) Write the answer accurate to 3 significant figures.
c) Write your answer to part b) in standard form.

3. The diameter of the Moon is approximately one quarter of the diameter of the Earth. The Moon's diameter is 3,476 km.

a) Write this number in standard form.
b) Calculate the circumference of the moon giving your answer in standard form to three significant figures.

4. The Moon is, on average, about 384,000km from the Earth.
a) Write this distance in standard form.
b) If a spacecraft travels to the Moon and back again, approximately how far has it travelled? Give your answer in standard form.

Our solar system

Our Earth is just one of nine planets which circle round the Sun. Here are their vital statistics starting with the planet nearest to the Sun.

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Planet	Diameter (km)	Planet	Diameter (km)
Mercury	4,878	Saturn	120,000
Venus	12,100	Uranus	52,400
Earth	12,756	Neptune	50,450
Mars	6,790	Pluto	2,300
Jupiter	142,800		

3

1. The diameter of the Earth can be written in standard form as 1.2756×10^4 km. Copy the list of planets above and write each of their diameters in standard form.

2. List the planets in order of size, starting with the smallest.

3. To get an idea of how the planets' sizes compare, you are now going to do a scale drawing on A3 paper. You need to draw circles for each of the planets. It is a good idea to draw Jupiter in a corner first and then Saturn. The radii for the circles are as follows: Mercury, 0.35cm; Venus, 0.85cm; Earth, 0.90cm; Mars, 0.50cm; Jupiter, 10cm; Saturn, 8.40cm; Uranus, 3.65cm; Neptune, 3.50cm and Pluto, 0.15cm.

You can see that Earth is a rather small planet but it does have some great advantages over the others. To see what these are we will look at some more "planet statistics".

Planet	Average distance from Sun in km	Planet	Average distance from Sun in km
Mercury	5.79×10^7	Saturn	1.427×10^9
Venus	1.08×10^8	Uranus	2.87×10^9
Earth	1.496×10^8	Neptune	4.497×10^9
Mars	2.279×10^8	Pluto	5.9×10^9
Jupiter	7.78×10^8		

4. Mercury is, on average, 57,900,000 km from the Sun. Copy the list of planets and write their average distances from the Sun in full in the normal way.

5. Which planet is approximately ten times as far away from the Sun as Earth?

6. Which planet is approximately one hundred times as far away from the Sun as Mercury?

The outer planets, Jupiter, Saturn, Uranus, Neptune and Pluto, are a long way from the Sun and so are very cold. The temperature in the cloud layers on Neptune has been estimated to be -220°C. **So Earth's first advantage is its distance from the Sun.**

The inner planets are Mercury, Venus, Earth and Mars. These are closer to the Sun but all except Earth are barren, rocky places with little or no water. Approximately 71% of the Earth's surface is covered in water. All life depends on the presence of water. **So Earth's second advantage is the presence of water.**

Mars and Mercury have little or no atmosphere and so suffer extremes of temperature too great for living things. Venus and Earth each have atmospheres which act like blankets and keep the planet temperatures steady. However, the mix of gases in the atmosphere on Venus causes a super-greenhouse effect. Venus suffers from temperatures of about 500°C!

So Earth's third advantage is its atmosphere.

4

Are we just lucky to have the right conditions for life on Earth? Some scientists think so ...

We are the way we are because the universe is the way it is ... and not vice versa.

Felix Pirani

Others believe the opposite ...

... it's not just 'any old world', but it's special and finely tuned for life because it is the creation of a Creator who wills that it should be so.

John Polkinghorne

Science cannot prove or disprove these statements. They are statements of personal belief. We all make up our own minds what to believe once we have looked at the different points of view.

Write a short summary of the two sides of the argument above. Discuss your ideas with a friend or with the class.

The Milky Way

Let us now look a bit further into our remarkable Universe.

Our Sun is a medium-sized star in our galaxy, the Milky Way. On a clear night you can see the Milky Way stretched out across the sky like a dim trail of light. No one knows how many stars it contains, one estimate is 10^{12}. So the mass of the Milky Way is estimated to be about the mass of the Sun multiplied by 10^{12}.

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5

Give all your answers in standard form.

1. If the mass of the Sun is 1.989×10^{39} kg, use the information given above to calculate the approximate mass of the Milky Way. Give your answer to 1 significant figure.
2. The diameter of the Sun is 1.4×10^{6} km. Calculate the circumference of the Sun. Give your answer to 2 significant figures.
3. The Sun converts 1.26×10^{14} tonnes of hydrogen into energy every year. If it has enough hydrogen left for another 6×10^{9} years, how many tonnes of hydrogen does it contain? Give your answer to 2 significant figures.
4. Using the data in question 3, calculate the number of tonnes of hydrogen that the Sun will use up in the next 9 million years. Give your answer to 2 significant figures.
5. It takes the Sun approximately 250×10^{6} years to move around the centre of our galaxy. Write this number in standard form.

The Universe

Our galaxy, the Milky Way, is just one amongst many scattered like dust throughout the vastness of the Universe. Each galaxy is a swirling pool of millions of stars.

6

For the following questions, give all your answers in standard form.

1. The star, Betelgeuse, is part of the constellation Orion. Betelgeuse has a diameter approximately 600 times the diameter of our Sun. Our Sun has a diameter of 1.4×10^6 km.
   Giving your answers to 2 significant figures, calculate:

   a) the diameter of the star Betelgeuse;
   b) the circumference of the star Betelgeuse.

2. The Andromeda galaxy is twice as massive as the Milky Way. The Milky Way is about 10^{12} times the mass of the Sun. If the Sun has a mass of about 2×10^{39} kg, calculate the approximate mass of the Andromeda galaxy.

All scientists agree that the scale and complexity of the Universe make it truly awesome. Some believe that it has all come about as a matter of chance, but others believe that they have found too many "coincidences" in the delicate balance of conditions throughout the history of the Universe. It has been said that the probability of life emerging within the Universe "by chance" is about the same as the probability of a tornado blowing through a scrap-yard and producing a jumbo jet!

What do you think?

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Light years away

Distances in deep space are so vast that they are measured in light years.
Light travels faster than anything else at a speed of 3×10^5 km per second.

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7

1. Giving all your answers in standard form, how far does light travel
   a) in one minute?
   b) in one hour?
   c) in one day?
   d) in a year of 365 days?
   e) round your answer to d) to 3 significant figures.

Your answer to part e) is a **distance** but it is called **one light year**. Check this answer with your teacher before going on to the remaining questions.)

In each of the following questions, give your answers to 2 significant figures.

2. The Andromeda galaxy is the most distant object we can see with the naked eye. It is 2.3×10^6 light years away from Earth. How far away is Andromeda in km?

3. At its widest point, the Milky Way is approximately 3.2×10^4 light years across. How far is this in km?

4. The approximate length of the Milky Way is 1.3×10^5 light years. How far is this in km?

5. Our Sun is approximately 2.6×10^4 light years from the centre of the Milky Way. How far is this in km?

6. a) If the Earth is 1.496×10^8 km from the Sun and Mars is 2.279×10^8 km from the Sun, how far is it from Earth to Mars when all three are in a straight line with the Sun between Earth and Mars? Give your answer in km and in standard form.

   b) Use your calculator to repeat part a) when all three are in a straight line with Earth between the Sun and Mars. Give your answer in standard form.

   c) When Earth and Mars are in the position described in part b), a spacecraft travels from Earth to Mars. If the spacecraft were able to travel in a straight line, how fast would it have to travel in order to complete the journey in three months? Assume that Mars and Earth do not move further apart during the journey, and that each month has 30 days. Give your answer in km per hour.

   d) In fact, the spacecraft can travel at 1.1×10^5 km per hour.
   How many days will it take to cover the distance? Give your answer to the nearest day.

   e) Give a reason why, in reality, the spacecraft in part d) would actually take longer to reach Mars.