Global Solar Partners

Energy for the 21st Century

Sharing ideas and information around the world

Solar Exchange Unit

Ages 12 - 16
English

TRIAL VERSION

BP SOLAREX
Solar Energy from BP Amoco

BP Amoco

SCIENCE ACROSS THE WORLD

The Association for Science Education

Solar Energy *Teachers' Notes*

This unit can be used during studies of energy resources or energy technologies in the first four years of secondary school. The unit also develops understanding of issues involving energy and sustainable development, and of citizenship within the "global village".

After working through the notes, students complete the **solar exchange form** as a group. This enables them to share the results of their research with other students around the world.

In this Unit, students will:

- **explore the importance of the sun through human history;**
- **compare the amount of solar energy around the world;**
- **research various applications of solar energy technology**
- **investigate the role of renewable energy in helping sustainable development;**
- **examine the basic costs and benefits of energy supply and use;**
- **explore how solar and other sustainable energy sources relate to climate change.**
- **develop their research and communication skills, using a variety of technologies (such as the Internet) and different languages.**

Scientific concepts

The solar system, energy storage and transfer, solar radiation, kilowatt-hours, electricity generation, electricity distribution grid, autonomous (stand-alone) electricity supply, photovoltaics (PV), uses of energy, economics of energy, energy and the environment, sustainable energy and development.

Prior knowledge and skills

Before starting work, students should have some basic knowledge about energy sources. It is also helpful if students are familiar with the units used for measuring energy (Joules or kilowatt hours). The optional experimental work requires basic data measurement and graphing skills. Older or more able students should also be able to manipulate simple mathematical expressions.

Teaching approaches

- After introducing the topic to the whole group, students may work individually or in small groups. Their results should be discussed as a whole class before completing the exchange form.
- Photocopies of the student pages are always useful, and it is helpful for students to briefly study the exchange form before they start work.
- Typically, individual parts of the unit require 1-2 hours of work. Research and/or activities could set as homework.
- If time is limited, seperate groups can work on different parts of the unit before presenting their results.

Guide to the Unit and sample answers

Each part of the Unit begins with an introduction and background reading. For the **exchange activity**, students are required to perform further local research which will help them to complete the **solar exchange form**. Each part also contains a small number of further questions. These are not compulsory, and they **are not** required for the exchange form. You may set a selection of further questions as extension activities, or as separate homework tasks if you wish.

Part 1 - The Sun in our Cultures

explores the **cultural significance** of the sun in the students' communities. Local examples can include religious icons, buildings, street names, poems or folk tales.

Part 2 - Solar Energy around the World

includes a world solar energy map. Students use this to find out how much solar radiation is available in their own and other countries.

For older students, the results can lead to a discussion of how solar energy may be captured. The optimum angle for a solar panel is when the sun's rays are perpendicular to its surface - this depends on the latitude and the time of day/year. A rule of thumb is that the panel angle from horizontal should be similar to the latitude angle at that location. If more energy is required in the winter, or in the morning (when the sun's angle is lower) the panel angle can be adjusted accordingly.

"Tracking" panels, which follow the movement of the sun across the sky, are able to gather more energy. However, this gain must be offset against the energy used to make the panel move.

Part 3 - Heat from the Sun

looks at **solar heating**. Students should look for examples of technologies for keeping buildings warm or cool as well as for other applications such as water heating.

Part 4 - Electricity from the Sun

concentrates on **photovoltaic (PV) technology** and its applications. Students should explore common small scale applications (such as for consumer goods) as well as larger ones such as home power or specialist uses.

Examples of the use of solar PV cells include watches, calculators, toys, battery chargers, lighting, traffic signals, marine applications, roadside telephones, garden fountains, for powering spacecraft etc.

Solar cells don't run down like batteries. However, without storage, energy is only available in daylight, or under artificial lights.

Part 5 - What does it Cost?

compares the financial and environmental **costs** of various energy sources.

In addition to CO_2, coal when burnt emits considerable amounts of other pollutants, including SO_x and NO_x. Acid rain is one result.

As well as developing sustainable energy sources, energy efficiency, demand-side management (eg. thermostats and timers) and user behaviour will all reduce our reliance on fossil fuels.

Part 6 - Exchanging your Information

Students will need a few copies of the Solar Exchange Form. These are used to send their findings to schools selected from the Registered Schools List.

Establishing communication with other

schools before starting detailed work on the Unit helps to keep the work in step so that feedback is more immediate. Some schools enjoy exchanging ideas and progress reports while they work on the Unit.

If you have Internet access, students can use the Glogal Solar Partners on-line database at http://www.asehq.org.uk/solar/welcome.html to select their exchange schools.

Please be sure to reply to exchange forms that you receive from other schools.

Part 7 - Comparing Information

is a guide to help students compare information after it is received from schools in other countries. When you have received exchange forms, compare them with your own results and discuss the responses with the help of the questions. You may also include your own questions, or suggestions from your students.

Part 8 - Additional Information

Includes extra data about solar energy worldwide, and references to reading materials and web-sites.

Part 9 - Solar Experiments

The experimental section of the Unit is optional; results are not needed to complete the exchange form. However you may select one or more experiments, depending on the time and equipment available, or on the age/ability of your students. If students complete any of the investigations, please include a selection of their results with the exchange form.

Science across the World

Solar Energy Exchange Form

Exchange school details:

Date

To
(teacher's name)

School

Address

Tel: (with international dialling code)

Fax:

E-mail

Your school details:

From
(teacher's name)

School

Address

Tel: (with international dialling code)

Fax:

E-mail

Web address of your school

We have been learning about solar energy, and we would like to exchange our findings with you and your class mates. We look forward to hearing from you, and to learning more about solar energy in your country. Here are the results of our research:

1. The Sun in our cultures

Name of example	Description	Other information

2. Solar energy around the World

The latitude where we live is .... degrees.

The solar radiation we receive on average per year is .... $kWhm^{-2}$

This compares with an average per year of .... $kWhm^{-2}$ for the following country: ....

We think that we receive more/less solar energy than .... for the following reasons:

- ....
- ....
- ....
- ....

3. Examples of solar heating in our community:

Application	Description	Other information

4. Examples of solar PV in our community:

Application	Description	Other information

We think that the following application would be a good future use for PV in our community:

....

....

....

....

Science Across the World [GB] ASE/BP Amoco 2000

5. What does it cost?

Electricity in our community costs .... per kWh.

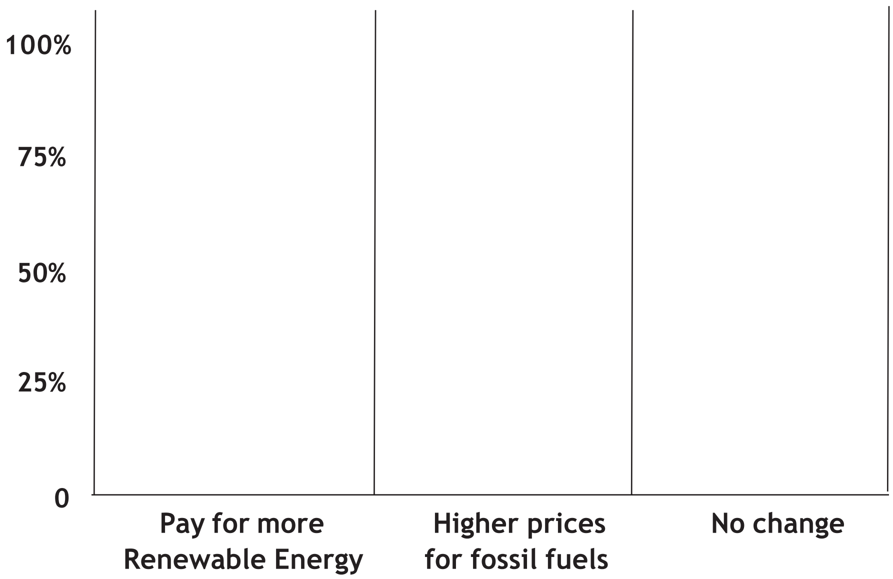
Most of our electricity comes from the following sources ***(please tick):***

Non-renewable sources: *Coal* ☐ *Oil* ☐ *Natural gas* ☐ *Nuclear* ☐ *Other* ☐

Renewable sources: *Wind* ☐ *Hydro* ☐ *Solar* ☐ *Geothermal* ☐ *Other* ☐

6. Class Survey

The following bar chart shows what our group would do about the impact of energy use



We have also included our work from the following experiments

☐ Measuring the sun's position

☐ Solar Hot Water

☐ Measuring the sun's energy

This completes our solar exchange form. We hope that you find our results interesting, and we look forward to receiving your exchange form.

Solar Energy *Student notes*

In this Unit, you are going to learn about solar energy. You will carry out research where you live and share your findings with students in other countries. The activities in parts 1 to 5 will help you collect the information you need to fill in the Solar Exchange Form. The activities are numbered to match the numbering on the Solar Exchange Form.

Part 1: The Sun in our Cultures

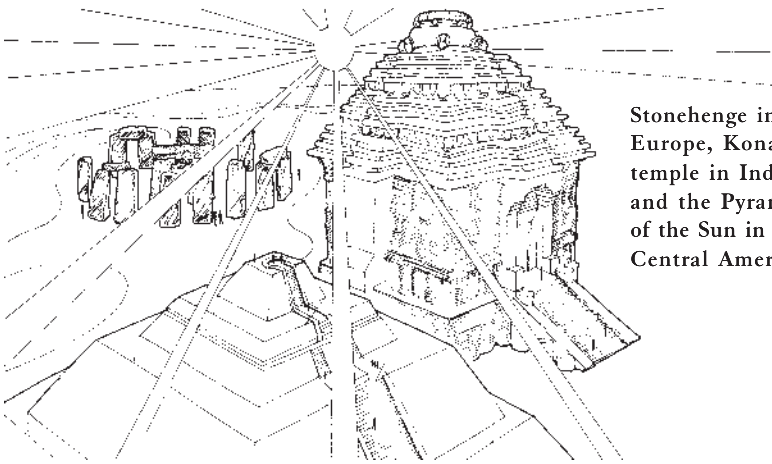
The sun is the source of energy on which life depends. the sun enables plants to grow, giving us the food that animals and humans eat. It also keeps the earth's atmosphere warm enough for living things to survive.

People have always known that the sun's energy was essential to life on earth. Since earliest times, sun gods have been important in many religions and cultures. Some of these are listed below:

Egyptian: Ra	***African:*** Liza	***Celtic:*** Lugh
Chinese: Ten Suns	***Norse:*** Freyr	***Polynesian***: Maui
Aztec: Tonatiuh	***Japanese:*** Amaterasu	***Inca:*** Inti
Roman: Apollo	***Inuit:*** Malina	***Hindu:***Surya

Solar Architecture

Our ancestors built incredible structures to celebrate the sun's importance to human-kind. There are places all over the world that have some special connection to the sun. These include ancient stone circles in Europe, Hindu temples in India and huge pyramids in Central America.



Stonehenge in Europe, Konarak temple in India and the Pyramid of the Sun in Central America.

Symbols of the Sun from around the world.

People often created images of the sun to illustrate their myths and legends. In ancient Greece, the sun god was called Helios. Every morning Helios rose from the east and drove his golden chariot across the sky. Early observers said that this movement showed that the sun circled the earth each day. Helios gave his name to the gas helium which was observed in the sun before being found on earth.

On the other side of the world in Central America, the Maya people built observatories to study the sun and stars. They based their calendar on the sun's movements measured from these observatories.

In Europe during the Renaissance age, the great astronomer and mathematician Nicholas Copernicus studied the Sun's place in our solar system, and realised its central importance:

"In the middle of all is the seat of the sun. For who in this most beautiful of temples would put this lamp in any other or better place than the one from which it can illuminate everything at the same time?"

Activity 1: The Sun in our cultures

Find examples of the sun in your county's religions, cultures or traditions. The examples could include stories and myths, temples, images or places with a connection to the sun. Now construct a table like the one shown below. The "other information" column can include a description of your examples and when you think they were created. The sample entries below come from a school in England.

Name of example	Description	Other information
Stonehenge	Ancient stone circle in Wiltshire, England	Built approx 2000 BC Some stones align with summer and winter solstices
Luguvallum	Old Roman name for Carlisle, England	Named after Celtic Sun God (Lugh)

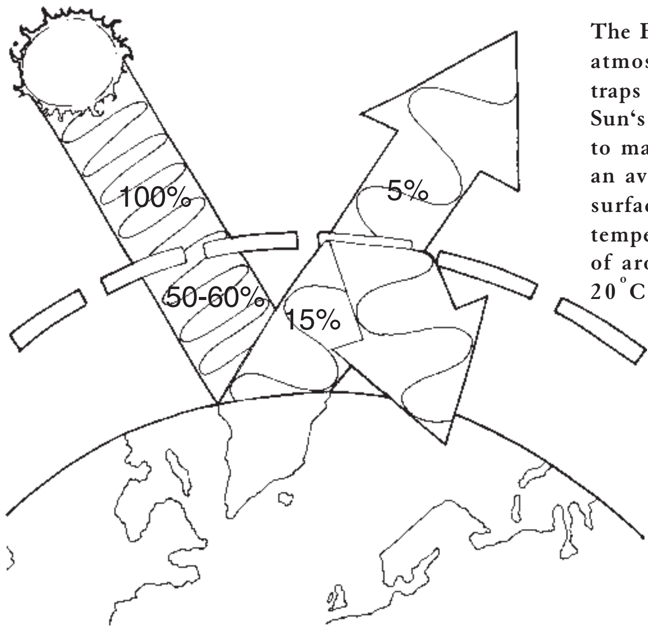
Further Questions:

- Why do you think that the sun has been important in so many myths and religions?
- Some early observers believed that the sun circled the earth each day, as shown by the path taken by the sun god Helios. The theories of Copernicus 2000 years later helped to change these ideas. Imagine that you are Copernicus in the 1540s, and write a short note to explain your new theory of the solar system's structure.
- Many images of the sun show its energy decreasing as the distance from the sun gets bigger. Write down other examples where energy intensity decreases as you get further from its source.

Part 2:
Solar energy around the world

Every day, the Earth's surface receives a huge quantity of energy from the Sun. This energy passes through the earth's atmosphere as "short wave" radiation. Some of this energy is radiated back into the atmosphere as "long wave" radiation. It is this long wave radiation that keeps our atmosphere warm. Another portion of the Sun's energy is absorbed by the earth's surface.

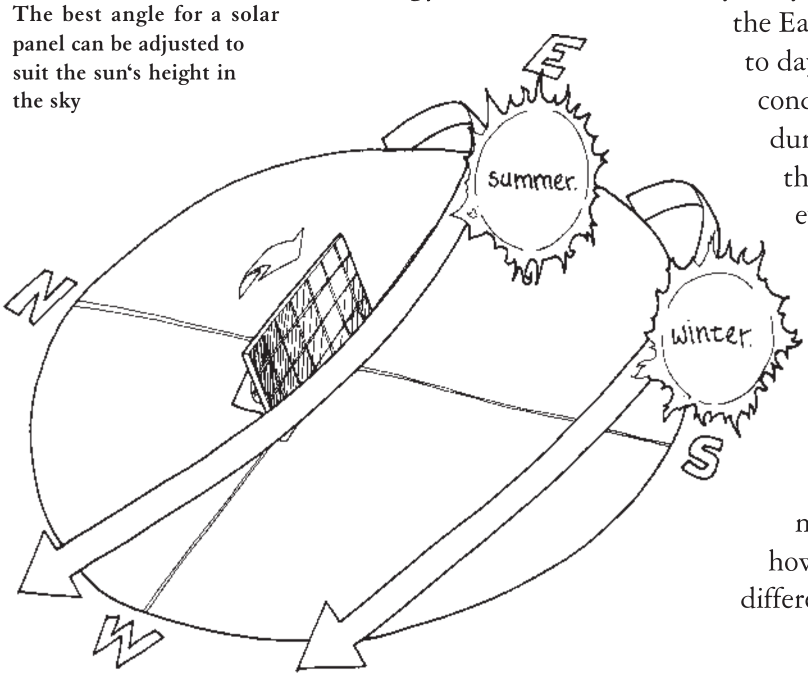
We can measure the energy of the sun at the surface of the Earth in units called 'kilowatt-hours' (or kWh for short). One kWh is the amount of energy used by a one hundred-watt light bulb in ten hours, or the energy that ten hundred-watt light bulb consume in one hour. In fact, your electricity meter at home or school measures the electricity that you consume in the same units - kWh. One kWh is the same amount of energy as 3 600 000 Joules.



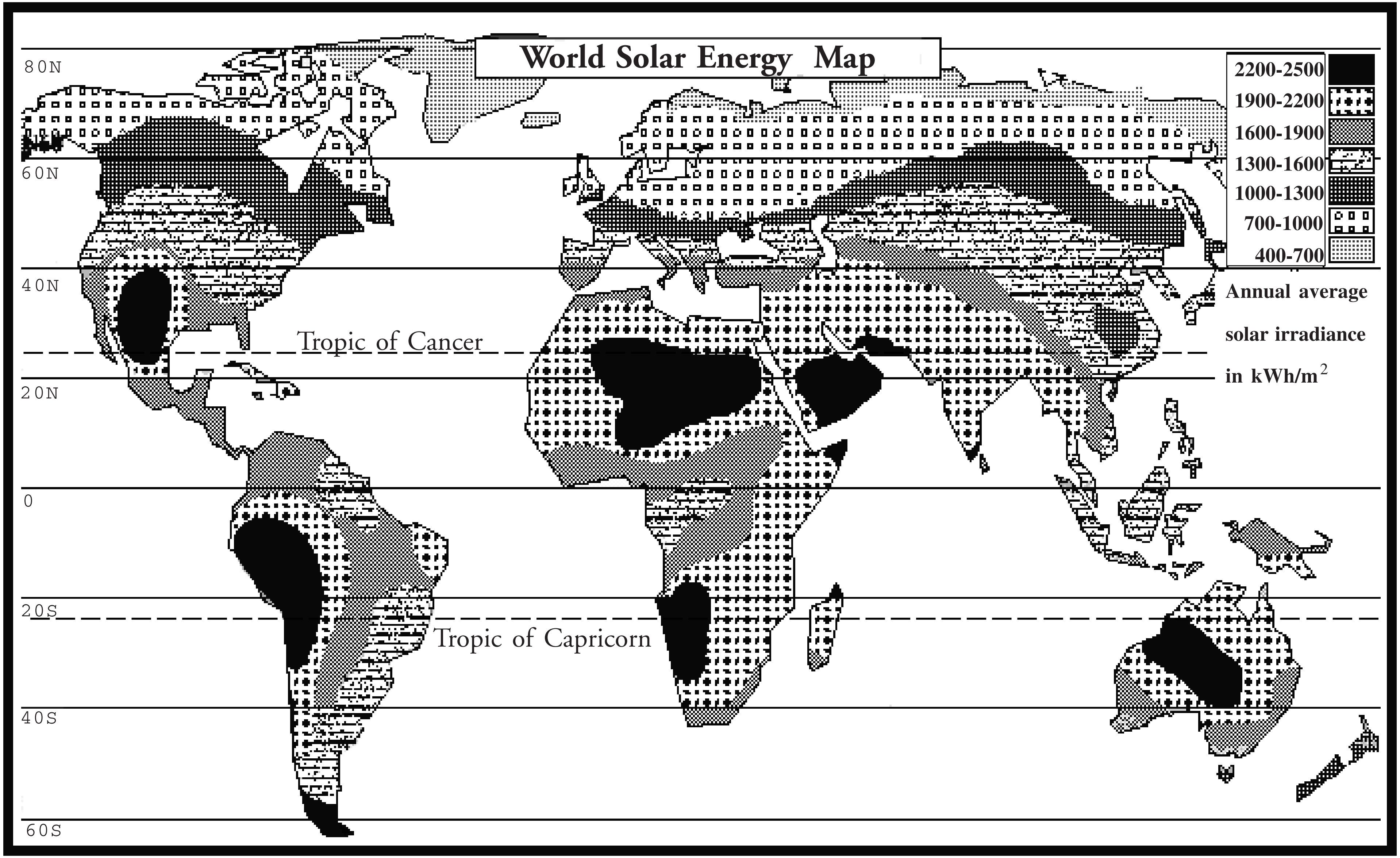
The Earth's atmosphere traps the Sun's energy to maintain an average surface temperature of around 20°C

During one hour, the earth's surface receives 420 million million kilowatt-hours per year of energy from the sun (4.2×10^{14} kWh). This is more energy than humankind uses in a whole year. However, capturing this energy for our uses is not always easy. The amount of solar energy at the Earth's surface changes from day to day, as the seasons and weather conditions change. It also changes during the day as the sun rises in the morning and sets in the evening.

Outside the Tropics, the path of the sun changes from winter to summer. The best angle for a solar panel can be adjusted to suit the sun's height in the sky



Measuring the energy that different locations receive from the sun helps us to find out how much solar energy we can use for our own purposes. The solar energy map on the next page shows how much of the sun's energy different places receive in a year.


World Solar Energy Map
80N
60N
40N
20N
0
20S
40S
60S
Tropic of Cancer
Tropic of Capricorn
2200-2500
1900-2200
1600-1900
1300-1600
1000-1300
700-1000
400-700
Annual average solar irradiance in kWh/m2

Activity 2: Assessing solar energy in our country

A) From the world solar energy map, write down the approximate latitude of your location.

B) Now use the map to find out how much solar radiation your country receives in a year.

C) From the map, select another country in a different colour zone. Write down how much solar radiation it receives in a year. Now list reasons why this amount is different to the energy received by your own country.

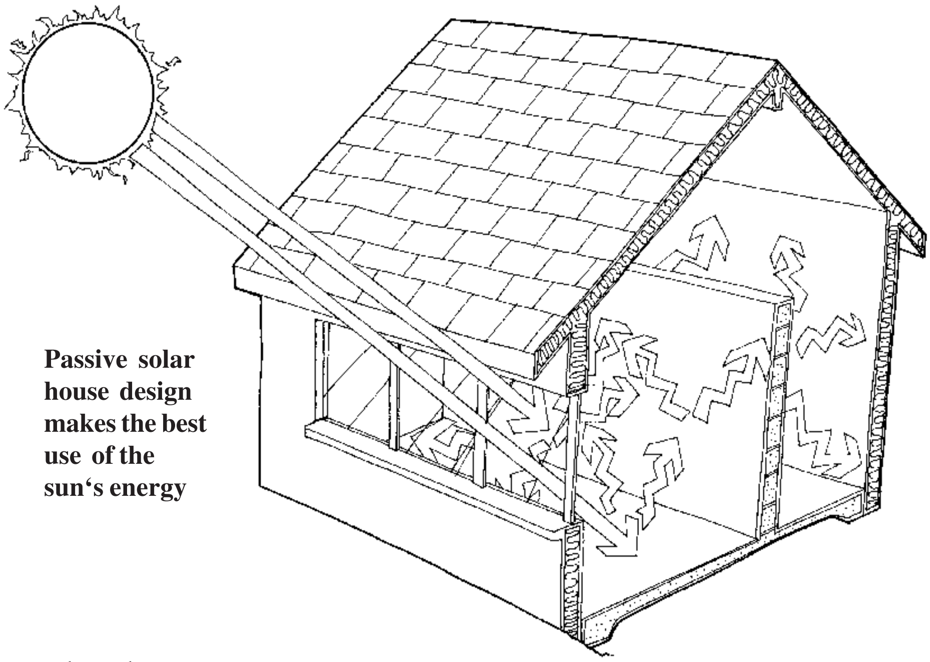
Further Questions:

- Imagine that a solar panel where you live is set at an angle from horizontal equal to your latitude angle. If you required more energy in the morning or the winter, how would you adjust the angle of your solar panel?

- Would more or less energy be available if your solar panel is able to move? If you think that more energy would be available, describe the movement of the panel. Try to explain your answer.

Part 3:
Heat from the sun

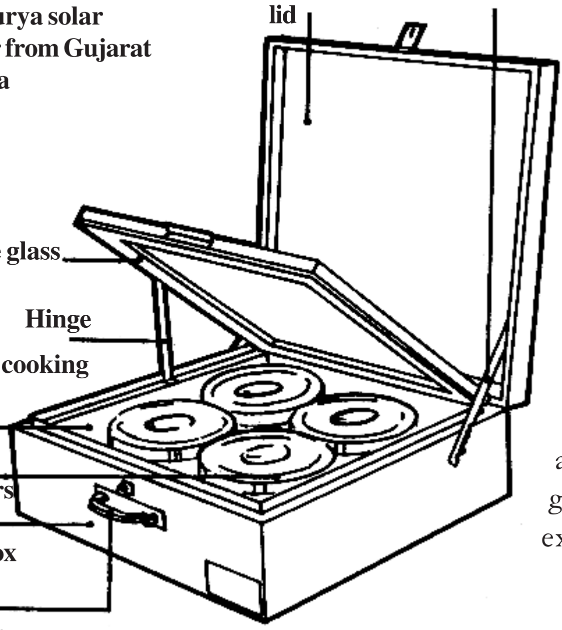
In tropical countries, many people live in houses which are designed to stay cool. Their homes have thick walls, small windows and overhanging roofs, so that the sun's rays do not penetrate inside. They may be painted white, to reflect sunlight away.



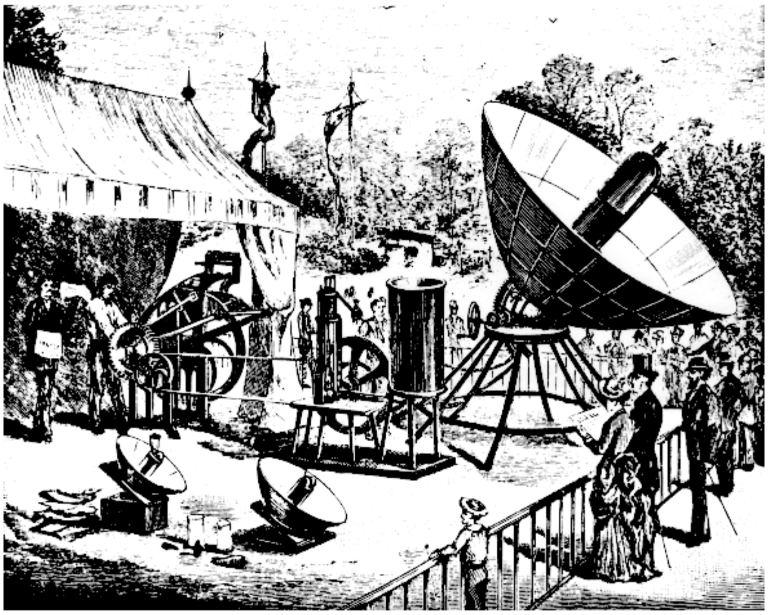
Passive solar house design makes the best use of the sun's energy

People who live in cooler countries have to heat their homes when the weather is cold. This costs money, and uses up valuable resources. By capturing and storing the sun's energy, their homes, schools and offices can be more comfortable. Large windows on the sunny side of the building can capture the sun's radiation. Smaller windows on the other sides, and well-insulated walls and roofs, can keep the warmth in. Materials like stone or concrete can store the sun's energy to be released in the evening when it is needed. This means that less fuel (such as wood, coal or gas) has to be used for heating.

The Surya solar cooker from Gujarat in India



In countries where wood or other fuels for cooking are scarce, food can be cooked in special boxes. Like a greenhouse, the box allows the sun's short wave radiation to enter, but doesn't allow the long wave radiation to get out. As the temperature inside the box increases to as much as 120 Celsius, the food inside gets hot enough to cook. These are all examples of **passive solar heating**.



Abel Pifre's solar-powered printing press, exhibited at the Gardens of the Tuileries in 1880

We can go one step further, with **active solar heating**. This means capturing the sun's energy in one place using panels or reflectors and then moving it to another place where the energy is used. Many houses around the world use active solar water heaters. This means that less fuel is burnt to heat their water. Active solar thermal technology can also generate steam. Using a solar powered steam generator, Abel Pifre developed a printing press in France in 1880. The three-metre diameter mirror reflected sunlight on to the steam boiler which was linked to a printing press. The press produced 500 copies every hour of the 'Sun Journal'!

Activity 3: Applications of solar heating

A) Look for examples of applications of solar heating in your country and write them down.

B) For each, describe the type of application. For example, is it used to keep buildings warm, to heat water or something else. Write your findings in a table like the one shown below. The sample entries come from a school in Greece

Name of example	Description	Other information
Greenhouse	A structure to keep plants warm and help them grow during our winter	Glass walls and roof trap heat to keep plants warm
Roof top water heater	Dark panels capture the sun's energy to heat domestic water supply	Our government provides subsidies for this technology

Further Question:

- Try to explain why these types of solar heating are found in your country. Would this technology work in other countries that receive more (or less) solar radiation than your own?

Part 4:
Electricity from the sun

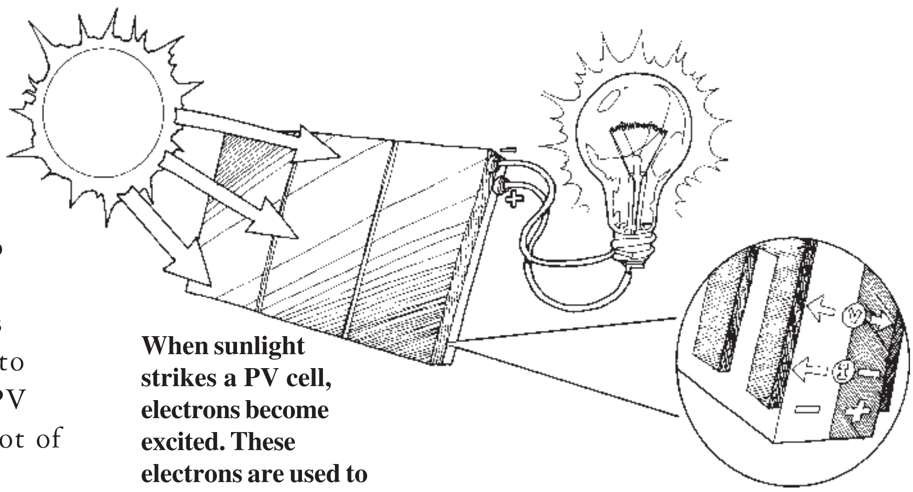
In 1839, a French scientist called Edmund Bequerel first discovered that some materials produced an electric current when exposed to light. This is called the photovoltaic (or PV) effect. 'Photovoltaic' means turning light into electricity.

Photovoltaic (PV) cells work in a similar way to the leaves of a tree. Leaves convert the Sun's light energy into chemical energy during the process of photosynthesis. However, unlike trees, PV cells capture the Sun's light energy and turn it into electrical energy:

Light Energy IN ➔ **Photovoltaic cells CONVERSION** ➔ **Electrical energy OUT**

The materials used to make PV cells are called 'semi-conductors'. Most PV cells are made from a semi-conductor called silicon. This is a very plentiful material - in fact, every grain of sand contains silicon, in the form of silicon dioxide (SiO_2).

A single PV cell produces only a small amount of electrical energy. To increase the energy, lots of PV cells are linked together in series to make a PV 'solar panel'. Solar panels can then be linked to form a large solar PV array producing a lot of electricity.



When sunlight strikes a PV cell, electrons become excited. These electrons are used to provide electrical power.

Solar PV systems produce electricity without noise, moving parts to wear out, or pollution. Solar PV systems can provide power for a wide variety of uses. Calculators, lights, fridges, homes and even whole villages or towns can use solar PV as their electrical energy source.

Activity 4: Applications of PV

A) You may have seen products (such as a calculator) powered by PV cells. Look for other applications of PV where you live, and use a table like the one below to record your observations. The sample entries come from a school in Malaysia.

Name of example	Description	Other information
Calculator	Small PV cells provide power when exposed to light	An inexpensive application of PV
Emergency phone	By a roadside to help drivers when their cars have broken down	The phone is a long way from an electricity supply

B) Now, in your study group, discuss applications that would be good future uses for PV in your community. Pick one future application, and write down why you have chosen it.

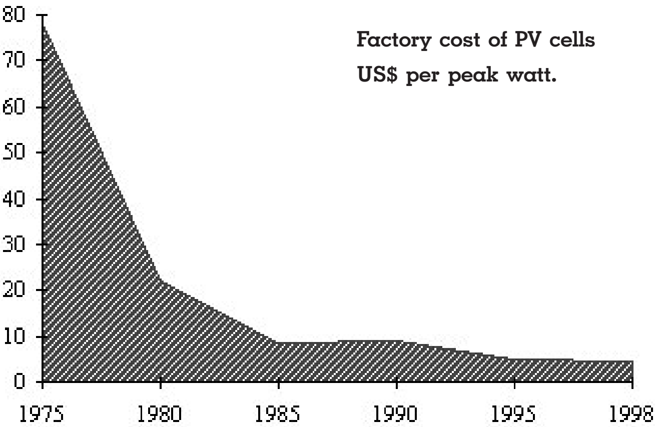
Further questions:

- Most pocket calculators are powered by batteries. What is the advantage of using solar cells to power a calculator? Are there any disadvantages?
- Solar PV has some disadvantages as well as advantages when compared to other energy sources. Discuss what these could be and write them down in a table. You can use the list in part 7 to help you.

Part 5:
What does it cost?

Many technologies that were once expensive are now much cheaper. These include things like calculators, digital watches, and personal computers. This is the same with solar PV technologies.

In some situations, PV electricity is already cheaper. For example, in remote areas of the world it is very expensive to build new pylons and wires to supply electricity. In these places, we say that it is more *cost-effective* to use PV.



When there is a main grid supply nearby, electricity from solar PV is still expensive compared to electricity from fossil fuels. It will take some years before the cost of PV electricity compares with fossil-fuel sources like gas or coal. However, when we think about fossil-fuel sources, we need to think about the environmental as well as the financial costs. These include:

1. **Taking fossil fuels out of the ground can cause damage to the environment. This includes damage caused by the extraction machinery and by the pollution that is a by-product.**
2. **Fossil fuels are not free. They cost money to bring out of the ground. This means that as fossil fuels run out, their price will increase.**
3. **Fossil fuels give off gases when they are burned. Some of these gases can cause environmental problems, such as acid rain. Others, such as carbon dioxide (CO_2) may be causing a change in the global climate - you may have heard the terms "Greenhouse Effect", "Climate Change" or "Global Warming".**

At present, in most countries the cost of electricity from fossil fuels does not include the cost of the damage they cause to the environment. This is called the "external" costs. If these were included, the price of this type of electricity would be higher. The table below compares the costs of electricity from various sources. **Figures are given in US cents per kWh.**

	Environmental	Financial	Total
Coal	2.5 - 16	4 - 9	6.5 - 25
Clean coal	1.2 - 4	4 - 9	5.2 - 13
Natural gas	0.6 - 1.2	6.3	6.9 - 7.5
Nuclear	2.5	3.8 - 7.5	6.3 - 10
Oil	2.5 - 7.5	7.5	10 - 15
Solar PV	0 - 0.3	34 - 74	34 - 75
Wind	0 - 0.1	5 - 14	5 - 14

In 1997, many governments from around the the world met in Kyoto, Japan to discuss global climate change. They agreed that countries must make an effort to reduce carbon dioxide (CO_2) emissions. In this way, the risk of possible further environmental damage due to climate change can be reduced.

To achieve these CO_2 reductions, it is important that we use more sustainable energy sources. Using solar PV technology to generate our electricity is one example of sustainable energy in action. Being more efficient with our energy and using solar energy directly for heating are other examples.

Activity 5: Energy and our environment

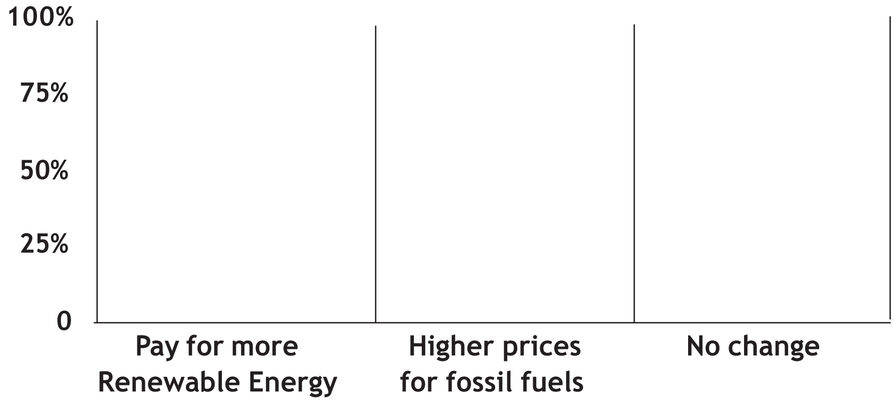
A) What is the main source of electricity where you live? Is it produced from sunlight, by burning fuels, or by some other means? What is the cost of electricity where you live?

B) Repairing our environment from the damage caused by fossil fuels costs money. In your group, discuss whether you think that the users of fossil fuels should pay for this damage. Count how many people think that fossil fuel users should pay more, and write down this number as a percentage of the group.

C) In your group, discuss which of you would be willing to pay extra to get more electricity from renewable sources. Write down the number who would pay more as a percentage of the group.

D) Finally, record the number of people who would prefer things to stay as they are.

E) Now record your results in a bar chart like the one below.



Further questions:

- Some countries encourage the installation of solar technologies. Find out if there are any incentives or promotions by your government or other institutions to encourage the use of solar energy.
- Look at the table showing the costs of various fuels. Of the fossil fuels, which do you think has the biggest impact on the environment when it is burned? Apart from possible global warming, suggest other impacts that may result from burning this fuel.
- Generating electricity from solar PV, wind and hydro is only one way of reducing CO_2 emissions. Give other examples of methods for reducing our reliance on fossil fuels.
- Little CO_2 is released when nuclear energy is used to generate electricity. Do you think that this is an example of sustainable energy? Give reasons for your answer.

Part 6:
Exchanging information with other schools

When you have finished working on the first five parts of this Unit, you will be ready to exchange information with students in other countries. You will use the exchange form on pages 4-7 for this. Here are some tips to make the exchange as successful as possible:

1. After completing your research, in your group decide which information you will include. It will help if you decide first which information will be interesting to students in other countries.

2. It is often interesting to send extra information to your chosen schools. This can include data, drawings, photographs or poems.

3. If you carry out any of the investigations in the 'Solar Experiments' section of the Unit, please include copies of your work sheets with your exchange form.

4. From the list of schools registered for this unit, you can send the exchange form to your chosen schools by fax, letter-mail or e-mail. Ask your teacher for this list.

Part 7:
Comparing information from other countries

When you have received information from your exchange schools, compare their information with your own. You can select suggestions from the following list, or use your own ideas.

1. Look at the examples of the sun in your exchange school's religions, cultures or traditions. How do they compare with yours?

2. Are the examples for the use of solar technologies the same for all schools? In your group, discuss reasons for any differences.

3. Find your partner schools on the solar energy map. For each location, How do the values for average solar energy received per year (in $kWhm^{-2}$ per year) compare? How does latitude affect the results? Why do some parts of the Earth receive more energy from the Sun in a year than others.

4. How does the cost of your electricity compare with your exchange schools? Do they come from the same sources? Discuss possible reasons for the differences.

5. What percentage of students from your exchange schools think that fossil fuels should cost more to include environmental costs? What percentage would pay more to increase renewable energy resources? Some students may have voted for both these options, while others may have voted for no change - can you tell how many from their bar charts? Are the results similar to your own?

Part 8:
Additional information

1. *Advantages and disadvantages of PV (in random order)*

a) No carbon dioxide or other pollution emissions
b) PV electricity is still more costly than electricity from fossil fuels
c) No need to burn finite resources (fossil fuels)
d) Storage needed for remote applications (eg. batteries)
e) Long operating life (20-30 years)
f) No noise during operation
g) Low efficiency - large areas of PV are needed for high power output
h) Plentiful supply of raw material (silicon)
i) Installation is simple (can be do-it-yourself)
j) Some risk of environmental problems from large scale manufacture
k) Low maintenance (repair and servicing) costs
l) No fuel costs
m) Wide range of applications
n) Little environmental damage during manufacture
o) Systems are "modular" - can be added to as needed.
p) PV has variations in energy output (daily and seasonal)

2. *CO_2 produced by burning different fuels and by generating electricity from these fuels.*

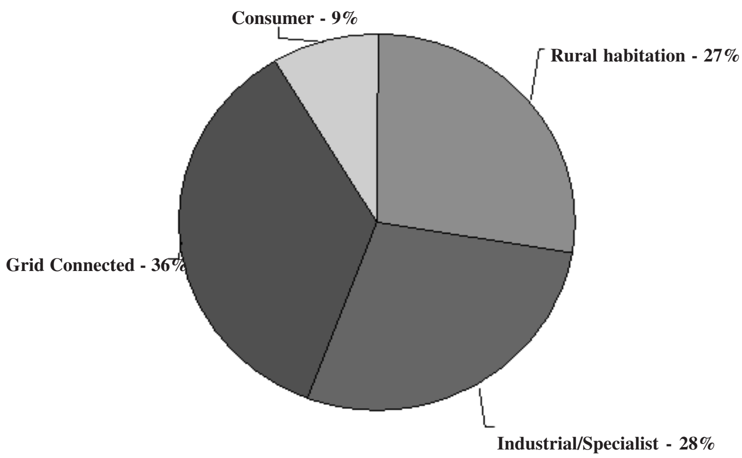
How the electricity is generated	Amount of CO_2 produced by burning (average)	Amount of CO_2 produced by generating electricity (kg per kWh of electricity)
By burning coal	2.4 kg from each kg of coal burned	1.0
By burning gas	1.8 kg from each cubic metre of gas burned	0.5
By burning oil	2.5 kg from each litre of oil burned	0.6
By using PV, wind or hydro technologies	-	0.001-0.004*
By using nuclear technologies	-	0.005*

** this is calculated from the energy required to manufacture the technology and the lifetime of the system.*

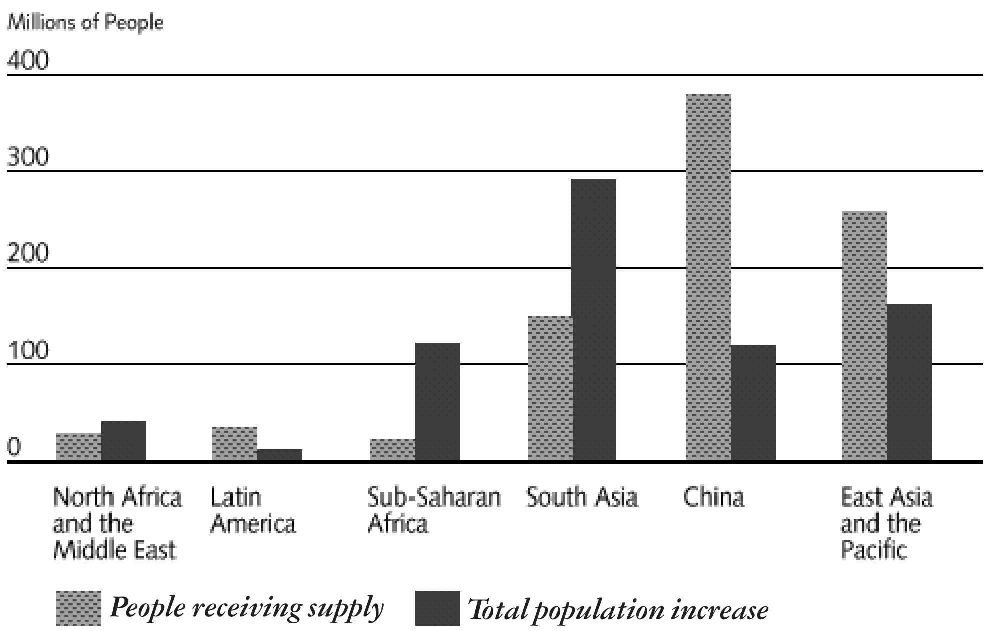
3. Amount of Sunshine around the world (average hours per year).

Cairo (Egypt)	3717	Rome (Italy)	2537
Bilma (Niger)	3681	Stockholm (Sweden)	1973
Giles (Australia)	3370	Lagos (Nigeria)	1862
Almeria (Spain)	3053	Syowa (Antartica)	1849
Tunis (Tunisia)	2907	Berlin (Germany)	1848

4. The Global PV market by sector (Worldbank, 1998)



5. Electricity in rural areas 1970-1990 - increase in number of people with a supply and total population increase by region (Worldbank, 1998)



4. Solar Glossary

Array A number of solar collectors connected together.

Battery An energy storage device composed of one or more electrolyte cells.

Diffuse Solar Radiation Sunlight scattered by clouds or pollution so that it arrives at the earth's surface from all directions. Diffuse radiation cannot be focused.

Direct Solar Radiation Solar radiation that arrives in a straight line from the sun. Direct radiation can be focussed using reflectors or lenses.

Energy The ability to do work. Different forms of energy can be converted to other forms, but the total amount of energy remains the same.

Fossil Fuels Fuels formed in the ground from the remains of dead plants and animals. It takes millions of years to form fossil fuels. Oil, natural gas, and coal are fossil fuels.

Grid An electricity transmission and distribution system.

Insolation The solar power density at a surface, usually expressed as Watts per square meter.

Joule A unit of energy or work. 1 Joule per second equals 1 Watt.

Kilowatt (kW) A unit of electrical power equal to one thousand watts, or to energy consumption at a rate of 1000 Joules per second.

Kilowatt-hour A unit of energy or electricity consumption of 1,000 Watts over the period of one hour.

Passive Solar (Building) Design A building that is designed so that its structure is used to heat and cool the building.

Photovoltaic cell An electrical device that converts light directly into electricity.

Renewable Energy Energy derived from natural resources that can not be depleted. These include moving water (hydro, tidal and wave power), biomass, geothermal energy, solar energy, and wind energy.

Solar Energy The energy transmitted from the sun (solar radiation). The amount that reaches the earth is equal to about 420 trillion kilowatt-hours per year. The solar intensity (sometimes called the irradiance or solar constant) above the earth's atmosphere is about $1370 Wm^{-2}$. At the earth's surface the "clear sky at noon" value is about $1000\ Wm^{-2}$.

Solar Thermal Systems Solar energy systems that collect solar energy to use as heat.

Tracking Solar Array A solar energy array that follows the path of the sun.

Part 9:
Solar Experiments Teachers' Notes

This is a separate section containing a number of solar energy experiments. These are an <u>optional</u> part of the Unit for teachers who wish to include a practical element in students' work. If students complete any of the experiments, please send a selection of their work to your exchange partners with the solar exchange form. A teachers' guide to each experiment is given below.

Experiment 1: Measuring the Sun's position

Here we consider how the position of the Sun in the sky affects the amount of solar energy available to us. The text also explains the units (kWh) used for measuring solar energy. 1 kWh is the same as 3.6×10^6 J.

Students are asked to monitor the position of the Sun. Two methods are suggested, depending on the equipment you have available.

At the sun's highest point, it shines from the south (180°) in the northern hemisphere and from the north (0°) in the southern hemisphere. Outside the tropics, the number of daylight hours and the average intensity of the sunlight both increase in summer. Working out the angle of the sun at noon can present difficulties. Here are two ideas:

- Make a scale drawing of the stick and shadow length on squared paper and use this to measure the angle of the sun with a protractor.
- Measure the height of the stick (x) and the length of the shadow at noon (y). The angle of the sun (A) may be found using the relationship, tangent of angle A = x/y

Use tangent tables or a calculator with trig. functions to find angle A.

Extension idea: Datalogging

Use a PV cell or light sensor connected to a datalogger to record the light level during the day. A graph can be printed out and included as extra information with the exchange form. If a *power vs. time* graph is plotted, integration of the area under the curve will give the total energy. Times of sunrise and sunset can also be obtained from the graph.

Note: For a PV cell, use only current readings as the input. Voltage readings from a PV cell are not proportional to light intensity.

Extension idea: Electrical power

By taking voltage readings from the PV cell at maximum current, the concept of electrical power ($W = I \times V$) can be introduced.

Extension idea: Solar power density

For older or more able students, a simple estimate of the sun's power per square metre can be calculated using PV cells. From the conversion factor of the PV cell and the area of the cell, solar power density J_{sol} can be found by using

$$J_{sol} = \frac{I_{max} \times V}{A \times C_{pv}} \quad \text{Wm}^{-2}$$

where I_{max} is the maximum current, output, V is the voltage across the cell, A is the area of the cell in m^2 and C_{pv} is the light-to-electrical energy conversion factor (typically 0.10 or 10% for crystal Si cells). Results can be compared with those obtained from experiment 2.

Experiment 2: Solar Hot Water

In this experiment, the energy absorbed by dar-coloured water when placed in direct sunight is measured as a temperature increase. When the bottle is placed in directsunlight, it absorbs energy and its temperature starts to rise. The ink or dye ensures that little energy passes straight through. By starting the experiment about 2^{o}C below the ambient temperature, and continuing until it is about 2^{o}C above, the heat gains and losses are cancelled out.

Experiment 3: Measuring the Sun's energy

This experiment is intended for older or more able students. A step-by-step student worksheet is included. For this investigation, the following assumptions are made:

- Most of the sun's energy is absorbed by the water in this experiment - we ignore the small amount absorbed by the plastic bottle.
- The mass of water is 1kg since the volume is 1 litre (1000ml).
- The equation used to calculate the energy absorbed by the water (needed for step 3 in the calculation):

  Energy Absorbed $= m\,c\,(\Delta T)$

  Where m = the mass of the water in kg, c = specific thermal capacity of water (4200 J kg^{-1} K^{-1}), ΔT = change in temperature in K or Celcius

- The full equation used to calculate the intensity of the sun:

  $$\text{Sun's power density } J_{sol} = \frac{m\,c\,(\Delta T)}{\Delta t\ A}\ \text{Wm}^{-2}$$

  Where Δt = time in seconds and A = the area measured in Step 1 in m^2. The units are watts per square metre (Wm^{-2}).

  A photocopiable worksheet for students appears at the end of the student notes.

  A test experiment was carried out in July at latitude 48^{o}N.

The data were:

Mass of water = 1kg

Specific thermal capacity of water = 4200 Jkg^{-1}K^{-1}

Rate of change of temperature
= 0.25 K per minute
= 0.004 K per second

Area of smallest shadow = 210 x 95 = 19950 mm^2 = 0.02 m^2

$$\text{Solar power density } J_{sol} = \frac{1 \times 4200 \times 0.004}{0.02}$$

$$= \mathbf{840\ Wm^{-2}}$$

Lack of perfect absorption and loss to the surroundings result in the rather low value.

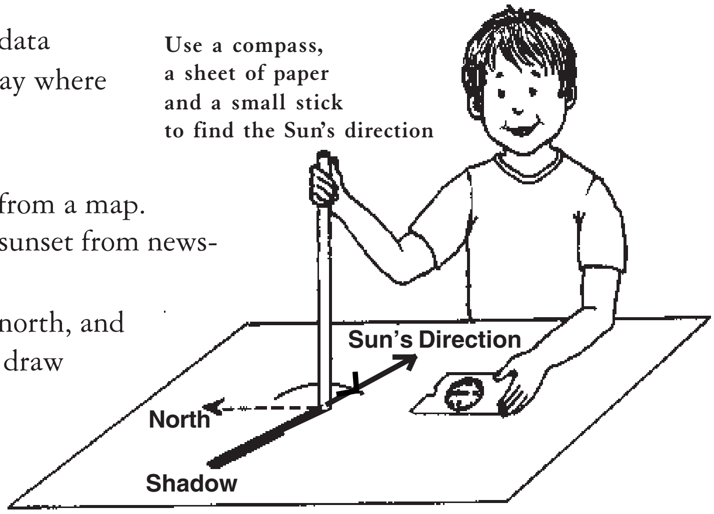
Solar Experiments *Student Notes*

Experiment 1: Measuring the Sun's Position

In this activity, you are going to obtain data about the sun's position and length of day where you live.

Before you start:

- Find out the latitude where you live from a map.
- Find your local times for sunrise and sunset from newspapers.



In both methods, use a compass to find north, and mark this on some squared paper. Then draw the sun's direction on the paper from a stick's shadow, as shown in the diagram below.

Measure the Sun's direction as a bearing (angle) from North (for example, 45° = North-East; 135° = South-West).

Safety: Never look directly at the sun, as this can damage your eyesight.

Method one: A home-made Sundial.

If possible, use a one metre long wooden pole sticking vertically out of the ground - this will make it easier to compare your data with your exchange schools'. Make at least 10 measurements of the length the shadow over a 2 hour period. Use trigonometry, or a scale diagram on squared paper, to estimate the angle of the Sun at different times.

Write down your measurements in a table like this - the numbers in the table come from a school in the UK:

Data from Sunnyside School, Latitude 55° N.
Data measured on 11th June
Time of Sunrise = 04:30 Time of Sunset =21:30

Time (local)	Time (UT or GMT)	Length of shadow (m)	Angle of sun (degrees)	Direction of Sun (degrees from North)
09:15	07:15	1.15	38°	104°
09:45	07:45	1.05	42°	111°
10:15	08:15	0.95	46°	120°
etc.				

- Plot a graph to show how the angle of the sun above the horizon changes with time. Find the maximum angle of the sun from the graph.

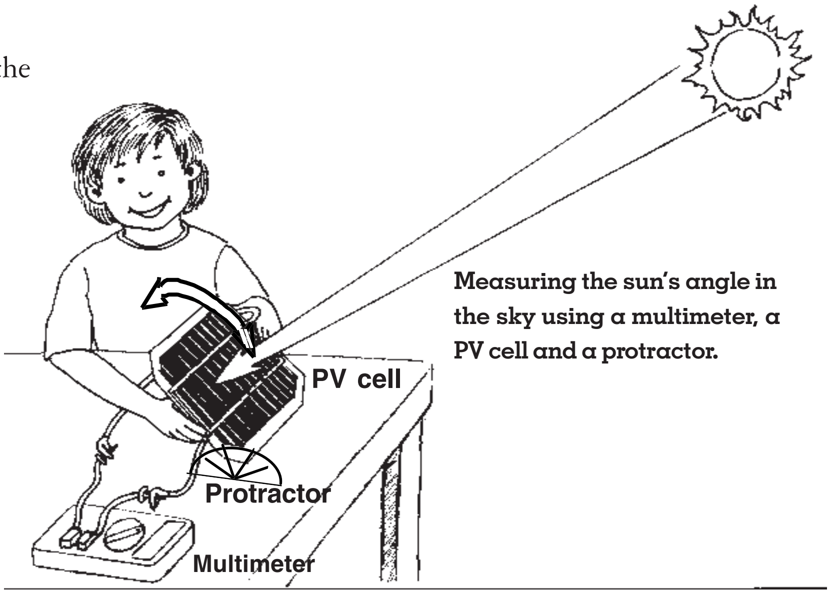
Method 2: Using a PV cell

If you have access to PV cells, connect one to a multimeter set to read current.

- Face the PV cell towards the sun and slowly change the angle of the cell until the current reading is at a maximum.
- Use a protractor to measure the angle of the PV cell from horizontal (see diagram). Note this down.
- Use the following equation to calculate the angle of the sun:

Sun angle $\alpha = 90 - \beta$

Where α is the angle (or altitude) of the sun from horizontal and β is the acute (small) angle of the PV cell from horizontal.



Measuring the sun's angle in the sky using a multimeter, a PV cell and a protractor.

Now fill in your table like this - the numbers in the table come from a school in the UK:

Data from Sunnyside School, Latitude 55° N.
Data measured on 11th June
Time of Sunrise = 04:30 Time of Sunset =21:30

Time (local)	Time (UT)	Maximum current (Amps)	Angle of sun (degrees)	Direction of Sun (degrees from North)
09:15	07:15	1.48 A	38°	104°
09:45	07:45	1.52 A	42°	111°
10:15	08:15	1.56 A	46°	120°
etc.				

Once you have collected your information, you can send your results and what you have found out from this experiment with the Solar Exchange Form.

Questions

a) Which direction would a fixed solar panel face so that it produces the most energy where you live?

b) To collect most energy from dawn to dusk, which would be the best angle for the panel (measured from the ground)?

c) Write down the latitude angle for your location.

d) Are there any other reasons why the times of Sunset and Sunrise are important in your country?

Solar Experiments *Students Notes*

Experiment 2: Solar hot water

In this experiment, you will use solar heating to raise the temperature of one litre of water. The experiment will be most successful on a sunny day. If the temperature outside is below freezing, then perform the experiment indoors by a window in full sunlight. You may include data from this experiment with the exchange form if you wish. Here is how to do the experiment:

Part A: temperature measurements

- Use a measuring jug to add exactly one litre (1000ml) of cold water to an empty plastic drink bottle.
- Add food dye or black ink to the water and stir so that the water is opaque (not possible to see through)
- With a thermometer, measure the temperature in the shade of the air around the bottle and note it down.
- Tie the thermometer to a string and lower it into the water. Stir the water and note the temperature.
- Place the bottle in direct sunlight, either outside or on a sunny window ledge.
- Check the thermometer every five minutes, stir the water and record the temperature each time in a table like this:

Data measured on 11th June at Sunnyside School, Latitude 55° N. Air temperature = 25°C.

Time (mins)	Water temperature (°C)	Temperature difference (°C)
0	24.5°C	- 0.5
5	25.0°C	0
10	25.7°C	0.7
etc.		

- Repeat the measurements for 40 minutes.
- Plot your readings on a graph showing time on the *x* axis and temperature on the *y* axis.

Questions

A) What is the maximum temperature reached by the water after 40 mins?

B) What is the maximum difference in temperature between the water and the air surrounding the bottle?

C) The line on your graph shows the rate of temperature change. Try and explain any variation in the slope of the line.

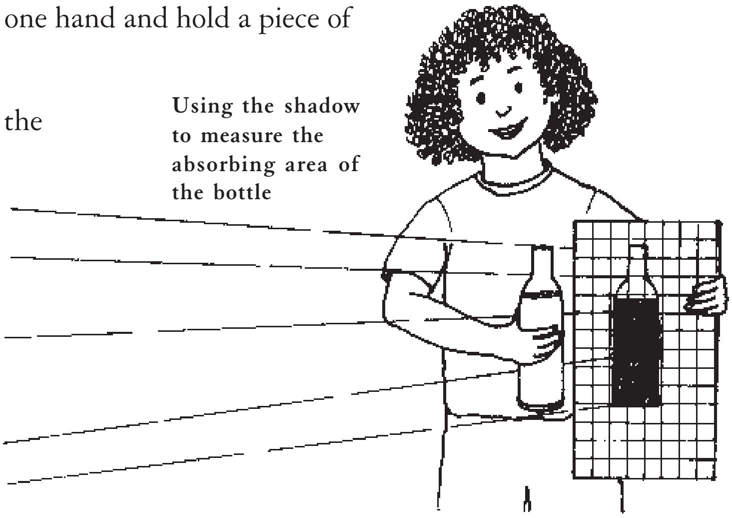
Solar Experiments *Students Notes*

Experiment 3: Measuring the Sun's Power

Using the results from experiment 2, you can now work out the energy coming from the sun on each square metre of ground every second.

Step 1: Find the area of the bottle that has been absorbing sunlight

- Hold the bottle in the sunlight with one hand and hold a piece of paper behind it with the other



Using the shadow to measure the absorbing area of the bottle

- Angle the paper until the shadow of the water in the bottle is the smallest that you can make it
- With the help of a friend, mark its area with a pencil
- Measure the length and width of the shadow in millimetres, or count the number of squares covered by the shadow
- Calculate the area in square millimetres and convert to square metres (divide by 1 000 000). Write down this value.

Step2: Find the temperature rise

The temperature readings at the start and finish of the experiment will give you the temperature rise in °C or K.

Step 3: Find the energy absorbed

Your teacher give you an equation to find the energy absorbed. Your answer will be in Joules or J.

Step 4: Find the rate of energy absorption

This can be found from your values for the total energy absorbed and the time taken for the experiment. The answer will be in J/s or Watts

Step 5: Find the sun's power per square metre

Use the values for the rate of energy absorption and the absorbing area of the bottle to find the Sun's power density in W/m^2

Student Worksheet: Measuring the Sun's Power

Step 1

Absorbing Area = …… mm^2

Absorbing Area in m^2 **A** = area in mm^2 / 1 000 000

= ……… / 1 000 000

A = …….. m^2

Step 2

Temperature rise *T* = max temp - min temp

= ………. - ………..

T = ………. K

Step 3

Energy Absorbed *E* = mass x specific heat capacity x temperature change

= *mcT* (NOTE: specific heat capacity *c* for water is 4200 J/kg/K)

= 1kg x 4200J/kg/K x …..

E = ……. J

Step 4

Rate of energy absorption *P* = Energy absorbed / time taken

= *E* / *t*

= ….. / 2400s (NOTE: *t* is 40 minutes or 2400 seconds)

P = …… J/s (can also be written as Watts *W*)

Step 5

Sun's Power Density *J* = Rate of energy absorption / area

= *P* / *A*

= ……/ ……

J = ……. W/m^2