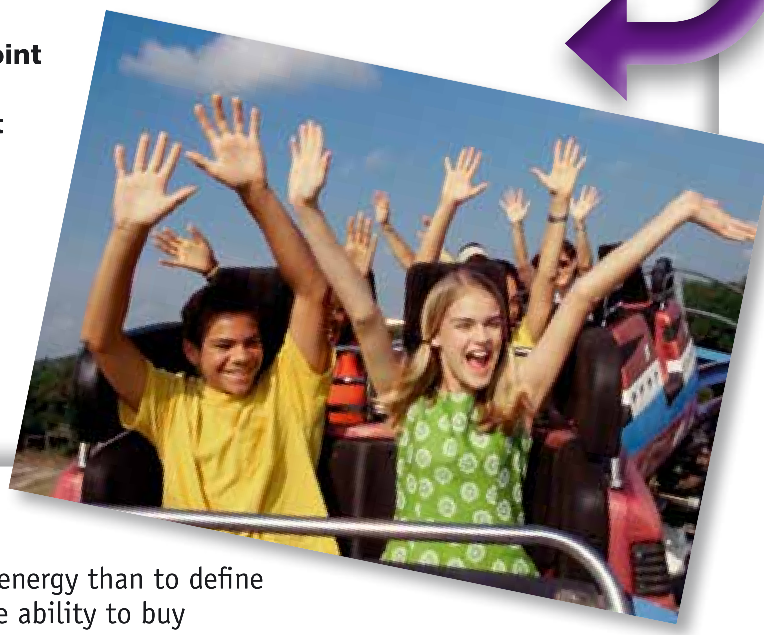
1.1 Energy stores

As a rollercoaster climbs to the highest point on its track, it transfers energy from its electrical supply to a gravitational store. It then rapidly shifts this energy to a kinetic store as it rolls downhill.



● **Figure 1** Is a rollercoaster most exciting when its energy is in the gravitational or the kinetic store?

→ What is energy?

It is easier to talk about what you can do with energy than to define what energy actually is. Just as money gives the ability to buy things, energy gives the ability to do things. Energy gives a car the ability to move, a kettle the ability to heat up water, and a light bulb the ability to shine.

→ Energy stores

Your money could be stored in a savings account or in your pocket, or it could even be placed in a shop's till if you use it to buy something.

Energy can also be found in different stores. There are eight types of **energy store**:

1 a hot drink holds energy in a **thermal store**
2 a moving car holds energy in a **kinetic store**
3 a stretched elastic band holds energy in an **elastic store**
4 a ball placed on a high shelf holds energy in a **gravitational store**
5 a battery and a log both hold energy in a **chemical store**
6 a thunderstorm holds energy in an **electrical store**
7 a magnet can hold energy in a **magnetic store**
8 a radioactive atom holds energy in a **nuclear store**.

● **Figure 2** What kind of energy is stored in a moving car?

➜ Shifting energy

Just as you transfer money from your pocket to a shopkeeper's till to buy something, energy can be shifted between the eight stores to do useful work.

- The elastic band's energy can be shifted to a kinetic store, when the rubber band is in flight, by **mechanical work**.
- The log's energy can be shifted to a thermal store in the surroundings by burning it. The energy transfer occurs by **convection** (**particle movement**) and by **radiation** of heat and light.
- The battery's energy can be shifted to a kinetic store in a spinning motor by **electrical work**.

➜ Dissipating energy

Energy stores can be concentrated, like in a kettle of boiling water. If you use this kettle of boiling water to try warm up a cold paddling pool, you have the same amount of energy in a more dilute form.

If you burn a log in a fireplace, the shift of energy to the thermal store of the surroundings is useful – it warms up your house. Often, though, when energy ends up in this store, it is not useful at all. When a motor spins, the moving parts rub against each other, producing heat by friction. Here mechanical work transfers useful energy to useless energy in a thermal store: a hot motor.

● **Figure 3** This pile of money represents the energy stored in the kettle of boiling water. How would you represent the energy stored in the paddling pool?

➜ Conservation of energy

The **law of conservation of energy** states that we can neither make, nor destroy, energy. All we can do is shift it from one store to another. When we have taken all of the energy from the chemical store of the wood, and transferred it to the thermal store of the surroundings, we have the same amount of energy as before, just stored in a different way.

Questions

1 Give an example of a situation in which energy is held in:
a) a gravitational store
b) an elastic store
c) a kinetic store.

2 A bow and arrow shift energy between stores. Can you name the energy stores, and give an explanation for the shift?

3 By what process is energy shifted:
a) from the gravitational store of a rollercoaster at the top of its track, to the kinetic store of the rollercoaster when it is moving fast at the bottom of the track
b) from the thermal store of the Sun to the thermal store of our environment here on Earth
c) from the chemical store of a battery to the thermal store of an electric heater
d) from the thermal store of a hot convection heater to the thermal store of the surrounding air?

Show you can...

Complete this task to show that you understand energy stores.

Write the names of the energy stores involved in:

a) a ball rolling along the ground
b) a kettle of hot water
c) the water in a reservoir high up in the mountains
d) the food you eat
e) a stretched catapult.

1.2 Heat transfer and the thermal store of energy

People use ice to cool their drinks down, but the ice does not 'give the drink its coldness' – rather, the drink loses some energy from its thermal store to the thermal store of the ice, and so the drink cools and the ice melts.

● **Figure 1** Energy from the thermal store of the drink will melt the ice, but what happens to the total amount of energy in the glass?

➜ The thermal store

The molecules in a substance are always moving, to a greater or lesser degree. In a warm liquid, the molecules move faster than in a cold solid. When the fast molecules bump against the slower ones, they give them some of their energy – the slower molecules speed up, while the faster ones slow down.

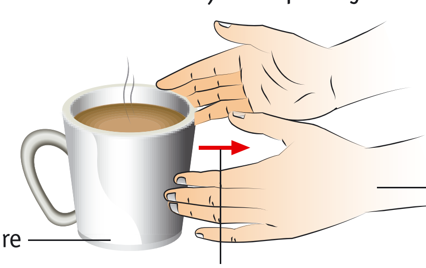
This is how a substance holds energy in a **thermal store**, and how heat passes that energy on to another substance.

➜ Warming and cooling

When a snowman melts on a warm winter's day, the snowman is warming up, but the heat from the air takes energy from the air's thermal store, so the air cools down.

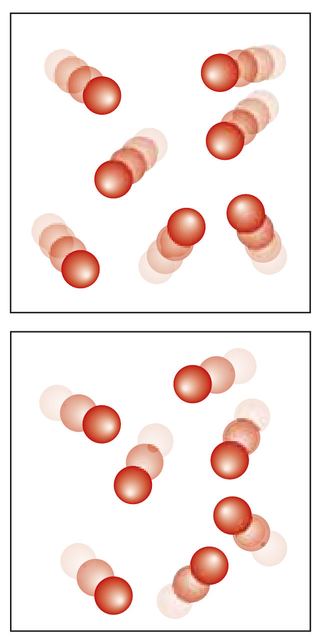
Holding a hot mug of tea warms your hands because heat transfers energy from the mug to your hands. The tea also cools down.

After their race, marathon runners wrap themselves in 'space blankets' to reduce heat transfer, so that they don't cool down (and warm up the air around them) too quickly.



● **Figure 3** A simple flow diagram shows how heat transfers energy from the mug's thermal store to your hands.

● **Figure 2** The particles in a warm substance (above) move faster than those in a cold substance (below)



➜ Heating and cooling

Hot chocolate in a polystyrene cup gradually cools down. It does this because it is losing energy. The energy transfers out of the hot liquid and into the surrounding room.

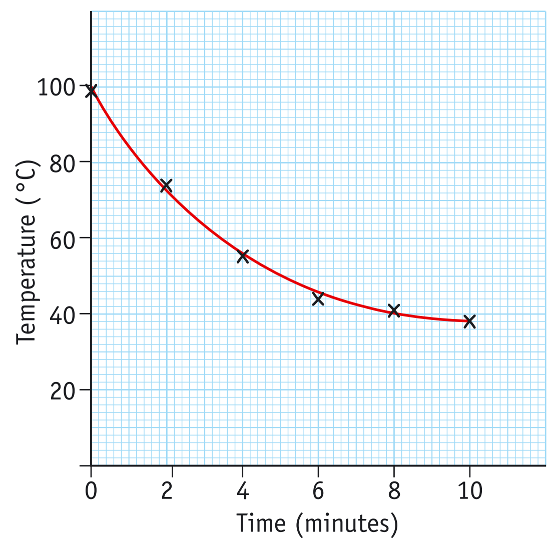
Energy can transfer between objects when one object is hotter than the other – so there must be a difference in temperature. In this case, the chocolate is hotter than the room. This is called **heat transfer**.

A drink of cold milk would gradually warm up if left in a warm room. This time the room is the hotter object, so the heat would transfer the other way, from the room to the milk.

Investigating temperature over time

You could investigate how the temperature of the hot chocolate varies with time. As temperature and time are both **continuous variables** (they can have any value), you should draw a line graph. The shape of the graph then helps you to draw a conclusion, for example about the time it takes the chocolate to reach a safe temperature to drink.

When you carry out investigations you need to measure the **variables** as accurately as you can. This means that your measurements of temperature and time are close to the **true values**. Some measuring instruments are more accurate than others, but even a good-quality measuring instrument can give inaccurate results if you make an error when you use it.



● **Figure 4** Plotting the temperature as time progresses clearly shows how a hot drink cools down

- Choose the best quality instrument available.
- Choose a **thermometer** with an appropriate range for your measurement.
- Remember to 'zero' the **stopclock** before using it.
- Remember to read the unnumbered marks in between the numbers that are marked on the thermometer's scale.

Questions

1 When ice is put into a glass of cola, how does the thermal store of energy change:
  a) in the ice
  b) in the cola?
2 In question 1, what happens to the total thermal store of energy contained within the glass?
3 Draw an energy flow diagram, similar to Figure 3, to show how energy transfers from a marathon runner to the environment.
4 Draw an energy flow diagram to show the energy transfers that happen when a snowman melts.

Show you can...

Complete this task to show you understand heat transfer and the thermal store of energy.

Draw a diagram to show how the particles move in a gas with:

a) a large thermal store of energy
b) a small thermal store of energy.

1.3 The gravitational store of energy and work done

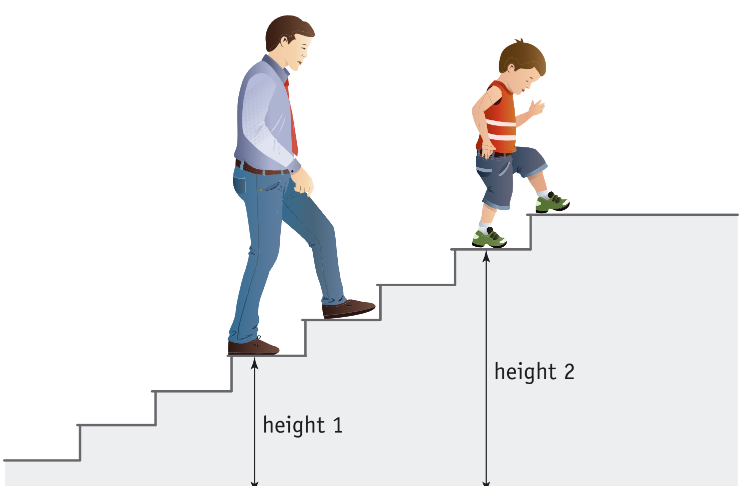
In October 2012 Felix Baumgartner jumped from a helium balloon 39 km above the Earth's surface and fell faster than the speed of sound. At 1360 km/h his kinetic store of energy was immense, but this energy must have come from somewhere.

● **Figure 1** Where did the energy in Felix's kinetic store come from?

→ The gravitational store

When you climb a staircase you transfer energy from the chemical store of your muscles to your gravitational store. The higher you climb, the more energy you transfer. A lighter person would need to transfer less energy to climb the same height, while a heavier person would require more.

We can see that the energy transferred depends both on the mass of the person and the height climbed.



● **Figure 2** You need to know your height and weight to calculate the energy in your gravitational store

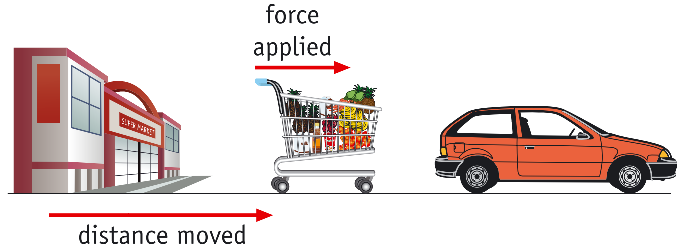
The amount of energy in the gravitational store is equal to the **weight** of the person multiplied by the height the person has climbed.

energy (in **joules**, J)	=	weight (in **newtons**, N)	×	height (in **metres**, m)

→ Work done

The weight of a person is a **force**, and the height they climb is a distance. We can write the equation on page 16 in more general terms to tell us the amount of energy expended, for example, when a shopping trolley is pushed along. In this case we call this energy the **work done**.

$$\text{work done (J)} = \text{force applied (N)} \times \text{distance moved (m)}$$



● **Figure 3** The work done depends both on how hard and how far you push

→ Frictional heating

The smoke produced by this dragster is caused by the heat produced by the tyres. They are spinning against the track and heating up due to **friction**. This heat burns the tyre rubber and causes smoke.

Friction is a very common cause of wasted energy. Whenever there are moving parts, friction transforms some of the energy of the moving parts into heat. To make machines more efficient you need to reduce the friction.

● **Figure 4** Are there any situations in which the energy lost due to friction is useful?

→ Gravitational to kinetic

When a lift moves from the ground floor to the top floor of a block of flats, the work done by the lift motor is equal to the energy transferred to the lift's gravitational store. When it drops back to the ground floor, the motor does not need to do any work – energy simply moves from the gravitational store to the lift's kinetic store.

Questions

1 Copy and complete the following sentences:
   a) When a skydiver falls from an aeroplane, energy is shifted from a .... store to a .... store.
   b) When a sledge is pulled along the snow, energy is shifted from a .... store first to a .... store, and finally to a .... store.

2 Write down three situations in which the work done against friction causes a heating effect. In each case, say whether the heating is useful or wasteful.

3 A man weighing 800 N climbs 5 m up a vertical ladder. How much energy does he transfer to his gravitational store?

4 A cyclist pulls the brake levers and exerts a force of 100 N at the brake blocks. If she travels 4 m while stopping, how much energy has been transferred from her kinetic store to the thermal store of the environment?

Show you can...

Complete this task to show that you understand work done and the gravitational store of energy.

Write a sentence to explain how the energy held in an object's gravitational store can be calculated by using the equation for work done.

1.4 Energy from fuels

Energy drinks are sold with the promise that they will enhance your performance, waking you up and giving you an 'energy boost'. But these effects are actually due to the caffeine in them, which in scientific terms contains hardly any energy at all.

● **Figure 1** What ingredient of these drinks contains the most energy?

There are many chemicals in the foods that we eat, and our body needs most of them, to a greater or lesser extent. But there are only three chemicals that act as stores of energy, or **fuel**. These are **proteins**, **fats** and **carbohydrates** (starch or sugar).

Look at the label on your breakfast cereal, or on the wrapper of your break-time snack. Does it mention energy? Is there a number given in **kilojoules** (kJ), or in the more old-fashioned term **kilocalories** (kcal)?

● **Figure 2** What does the nutritional label on your breakfast cereal tell you?

➜ Proteins, fats and carbohydrates

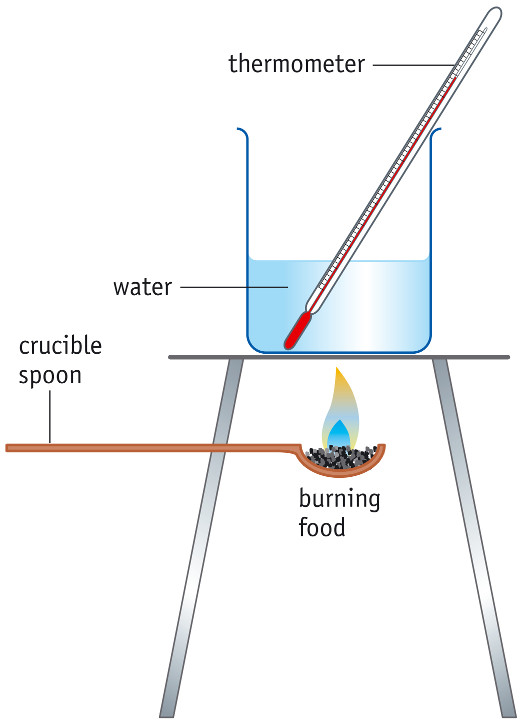
Our bodies **metabolise** (break down) the foods that we eat into their building blocks, which can be easily used to increase our chemical energy stores. Proteins are used by the body to repair damage and to build new cells, and so are not used for energy as much as fats and carbohydrates. Our bodies are good at storing fat, and when we eat more than we need it is packed away underneath our skin 'for a rainy day'. Carbohydrates are used in respiration, or stored on a short-term basis in the liver.

It's rather like saving up for a new bike by putting money into a savings account (fat), while keeping your pocket money in a moneybox, where you can dip into it from time to time (carbohydrate).

● **Figure 3** If we need energy to live, why are we told to eat a low-fat diet?

→ Comparing different foods

You can compare the amount of energy stored in different foods by using this apparatus. To make it a fair test you should use the same amount of food each time. You should also control other **variables** – use the same amount of water and the same starting temperature.



● **Figure 4** Burning transfers energy from the chemical store of the food to the thermal store of the water

The energy released from burning the food increases the temperature of the water. The food that releases the most stored energy will produce the largest temperature rise.

Unfortunately, lots of heat will be **dissipated** (lost) into the surroundings and so not all the heat is transferred to the water. This means the temperature rise may not be the true value. There could also be errors if the thermometer is not very accurate.

Questions

1. Which chemicals in the food you eat act as fuels (stores of energy)?
2. What other fuels can you think of? (Not ones that you would eat!)
3. A grown man needs around 10 000 kJ of energy per day. One gram of carbohydrate provides 16 kJ, one gram of protein provides 17 kJ, and one gram of fat provides 37 kJ. Use these numbers to explain why a man eating a high-fat diet is more likely to put on weight than one on a low-fat diet.
4. Nyan measured the temperature rise of two identical beakers of water when he burnt a peanut under one and a piece of popcorn under the other. Both foods weighed the same amount, but the water above the peanut got hotter than the water above the popcorn.
   a) What does this tell you about the peanut and the popcorn?
   b) Which food do you think contained more fat?

Show you can...

Complete this task to show that you understand fuels and energy.

Draw an energy transfer diagram for the experiment shown in Figure 4

1.5 Energy and power

Power tools are very useful when doing housework or gardening. A hedge trimmer will cut faster than a pair of shears, an electric drill works faster than a hand drill, and many people even have an electric screwdriver to help save time and effort.

● **Figure 1** What powers a lawnmower that does not run on electricity or petrol?

→ Power

All machines transfer energy from one store to another, but some do it faster than others. A more powerful kettle will heat up water faster than a less powerful one, and a more powerful car will have a greater acceleration than a less powerful one.

Power is the rate at which a machine does work, or the rate at which it shifts energy from one store to another.

● **Figure 2** The sports car has good acceleration, but does it actually have more power than the lorry?

→ Power of electrical appliances

Some electrical appliances have more power than others. The power of an electrical appliance is usually measured in **kilowatts** (kW). An appliance with a power of 1 kW (1000 W), will shift 1000 joules of energy in a single second.

Typical power ratings of appliances	
Appliance	**Power (kW)**
Kettle	2.0
Lawnmower	1.5
Microwave oven	1.0
Toaster	0.8
Television	0.2
Laptop computer	0.1

→ Energy efficiency

If you could design the perfect light bulb, it would transfer all the energy supplied as light. The **efficiency** of your perfect bulb would be 100%

Unfortunately there are no devices that are 100% efficient – they all waste energy in some way. In almost all devices, the wasted energy is lost as heat. Modern low-energy light bulbs produce much less heat than older bulbs do. They are more efficient.

total energy in (J) = useful energy out (J) + wasted energy out (J)

$$\text{efficiency (\%)} = \frac{\text{useful energy out (J)}}{\text{total energy in (J)}} \times 100$$

As energy is never created nor destroyed, you can work out the wasted energy if you know the input energy and the useful output energy. A light bulb with an input of 100 J might transfer 20 J of this to the surroundings as light. This mean it must transfer 80 J as heat, as the total energy out (20 J as light, 80 J as heat) must equal the total energy in (100 J). The efficiency of this light bulb (using the equation above) would be: $\frac{20}{100} \times 100 = 20\%$.

Modern **LED** bulbs are more efficient than 'energy-saving' **compact fluorescent bulbs**, which in turn are more efficient than old-fashioned incandescent (**filament**) **bulbs**.

● **Figure 3** If wasted energy is always lost as heat, could an electric heater be 100% efficient?

Questions

1 Which of the following is more powerful?
  a) a stereo system or a portable radio
  b) a mobile phone screen or a widescreen television
  c) a pocket torch or a light bulb

2 If you swapped the following machines for more powerful ones, what differences would you notice?
  a) a hairdryer
  b) a torch
  c) a leaf blower
  d) a toaster

3 The energy an appliance uses (in kJ) is equal to the power of the appliance (in kW) multiplied by the amount of time it is used (in seconds). Use the power ratings given in the table and calculate how much energy is used when:
  a) a kettle is used for 2 minutes (120 seconds)
  b) a microwave oven is used for 10 minutes (600 seconds)
  c) a television is used for 3 hours (10 800 seconds).

4 Calculate the efficiency of:
  a) an LED light bulb that transfers 95 joules usefully through light for every 100 joules it is supplied with
  b) a car that wastes 30 kJ through heat for every 40 kJ it releases from its fuel
  c) a lift that transfers 200 J to its gravitational store for every 800 J it transfers to the thermal store of the environment.

Show you can...

Complete this task to show that you understand power.

Write a sentence to explain why a television, with a power of 0.2 kW, will often use more energy in a day than a kettle, which has a power of 2 kW.

Presenting data

→ Television's hot!

Joel and Charlotte wanted to persuade their parents to buy a new television, so they looked up the energy performance of the leading models. They found out that, for the same sized television, the LED TV used 75 W, the LCD television used 110 W and the plasma screen TV used 210 W. In each case, the television only gave out 5 W of this energy as light, and 1 W as sound; the rest was transferred to thermal energy in the environment as shown in this table.

● **Figure 1** When buying a television, most people don't look at the energy consumption. Why not?

	Television type		
	LED	LCD	Plasma
Light emitted	5 W	5 W	5 W
Sound emitted	1 W	1 W	1 W
Heat emitted	69 W	104 W	204 W
Total energy used	75 W	110 W	210 W

Presenting data

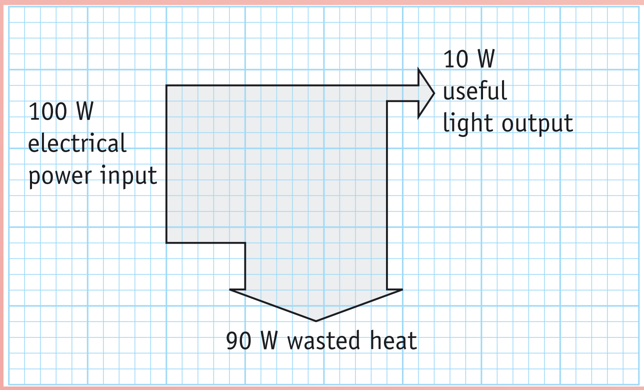
One of the skills scientists have to use is the ability to present their data in a meaningful manner, which helps the reader to understand the facts quickly and easily. Depending on what the data are, they could be presented as:

- a bar chart
- a pie chart
- a line graph
- a bubble chart
- a flow chart
- a **Sankey diagram**.

How to draw a Sankey diagram

A Sankey diagram is a bit like a flow chart, but one in which the width of each arrow indicates the amount of energy that is flowing into, or out of, the appliance.

In Figure 2, the incoming arrow is 10 squares wide, indicating 100% of the input power. The outgoing arrow on the right is only one square wide, which tells us that a filament bulb only transfers 10% (one square in 10) as useful light. Finally, the downward arrow represents all power that has been wasted – in this case it is nine squares wide, showing that 90% of the power is wasted as heat.



● **Figure 2** An old-fashioned filament light bulb is very inefficient

The task

Your task is to present these data in these various forms, and to decide which would be the best way for Joel and Charlotte to present the information to their parents.

Remember that the energy used in 1 second by a 75 W appliance is 75 J. So your labels can be in either power (in watts) or energy used per second (in joules).

If you are working as a group, divide the following tasks among yourselves.

1. Draw a bar chart showing the energy emitted by the LED television.
2. Draw a pie chart showing the energy emitted by the LCD television.
3. Draw a line graph showing the energy emitted by the plasma television.
4. Draw a bubble chart to show the energy used and the energy emitted by the LED television.*
5. Draw a flow chart to show the energy input (total energy used) and the energy outputs of the LCD television.
6. Draw a Sankey diagram to show the energy flow through a plasma television. For instructions on drawing a Sankey diagram, see below.

* To draw a bubble chart for the LED television, draw circles whose sizes are in proportion to the numbers in the table, e.g. one large circle of 7.5 cm radius, a smaller one inside this of 6.9 cm radius, and two more of radii 5 cm and 1 cm. Colour code and label each bubble.

Comparing the diagrams

When your group has finished drawing their graphs, charts and diagrams, compare them.

7. Each member of the group should say why their chart is good at presenting the data.
8. After all group members have spoken, decide on which method of presenting this data you think Joel and Charlotte should use when talking to their parents