COSMOS LESSONS

## Physics

# Energy Transfer: Taking the heat

Energy is needed to make anything happen, from riding a bike or burning a candle to lighting up our cities after dark. People invent machines to harness energy in new and exciting ways. Scientists are now trying to turn waste heat into useful electricity, making our machines more efficient than ever.

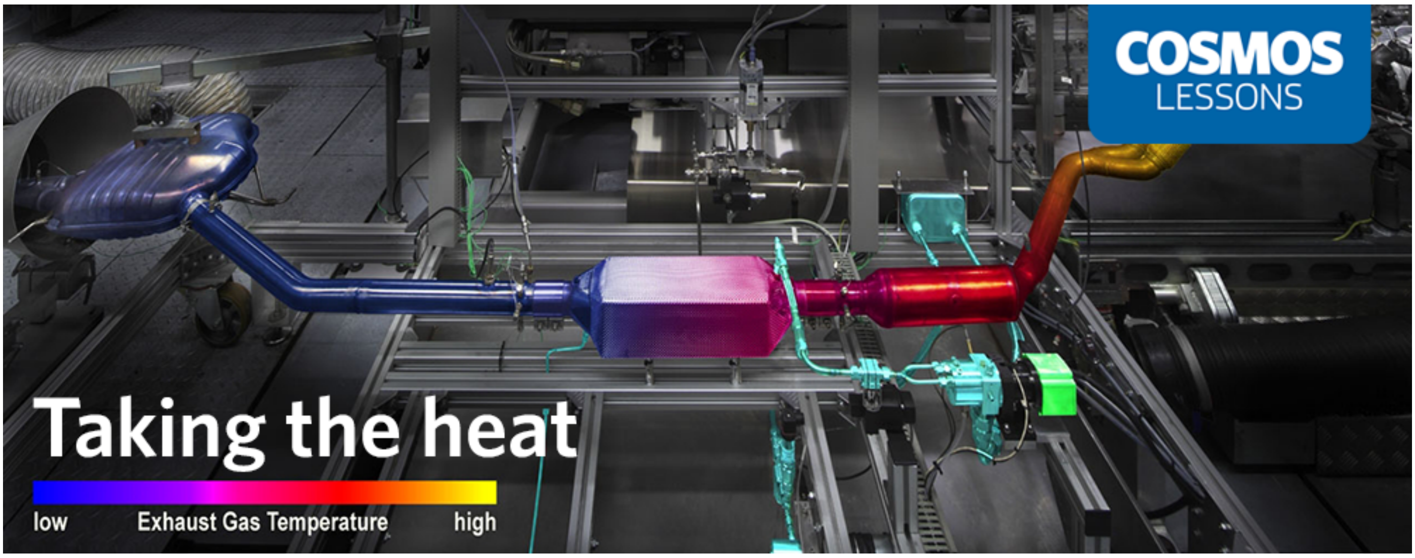
In this lesson you'll investigate the following:

- What sorts of energy are there?
- What's the difference between energy transfer and energy transformation?
- What are Sankey diagrams?
- How can we improve the efficiency of machines?

So get ready to transform your understanding of energy transfer!

This is a print version of an interactive online lesson. To sign up for the real thing or for curriculum details about the lesson go to **www.cosmosforschools.com**

# Introduction: Energy transfer




**Even though energy is all around us** – radiating from the Sun, stored in the food we eat, flowing through our computers and appliances – it's a precious resource that we need to use wisely.

Many of the ways we use energy are extremely wasteful. For example, some power plants convert only a third of the energy stored in coal into electricity while two thirds is lost in the form of heat. That's why there's increasing pressure to find ways of converting heat into useful electrical energy. This process is called thermoelectrics.

The theory is simple. If you heat up one end of a piece of thermoelectric material the electrons there will move away to the cold end where they can be tapped as a source of electricity. But the problems come when we try to make the process work on a big enough scale to be useful.

Engineers and scientists are on a quest to find the best materials to make this happen. Good thermoelectric materials need to have a rare combination of properties. They must be good at conducting electricity so the electrons can move, but not very good at conducting heat so that the hot end stays hot and the cold end stays cold.

So far that search has been disappointing, but one scientist in Chicago thinks he may have found a promising material. He says that tin selenide – a steel-grey crystalline solid – is very efficient at converting heat into electricity.

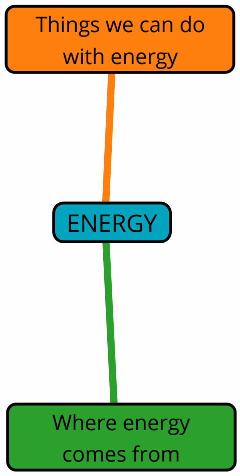
We don't know yet whether this is a breakthrough or whether the search must go on, but it's worth looking. A good thermoelectric material could transform the way we use energy, from how we recharge our phones to how we run our cars.

**Read or listen to the full *Cosmos Magazine* article here.**

## Question 1

**Construct:** Think about all of the situations in which you use the word "energy". Where do different types of energy come from? What sorts of things is energy useful for?

Unleash your brainstorm into the mind map below by entering as many ideas as you can come up with, even if you're not sure about them.



# Gather: Energy transfer



## Putting energy to work

If you have energy, you can do things – you can run or jump, dance or scream, ride a skateboard or swim across a river. And maybe, lying in bed on a Sunday morning, you've felt as though you don't have the energy to do anything at all.

But lots of things have energy, not just people and other animals. Just think of the whirring of your computer, the thundering power of a waterfall or the warmth and light of a bonfire.

Scientists say that in all of these cases – both human actions and natural changes – there is *work* being done. In this sense of the word, even sunlight is doing work when it warms your face and hands on a sunny day.

This brings us to the scientific definition of energy: ***energy* is the ability to do work.**

For example, *kinetic* energy is the energy of motion – moving things around is a kind of work. The faster an object is moving, the more kinetic energy it has and the more work it can do. Here are some other familiar types of energy:


Since energy is the *ability* to do work, it can be stored and then used at a later time – this is known as *potential energy*. For example:

- Any object that is raised up into a position where it can fall, roll or slide downwards has *gravitational* potential energy, even if it isn't using that energy to move right now. The higher something is, the more gravitational potential energy is stored in it.
- *Elastic* potential energy is stored in things like compressed springs and stretched rubber bands.
- *Chemical* energy is stored in the chemical substances found in batteries, wood, petrol, food and the cells of all living things.


## Question 1

**Complete:** Write the missing words into the right hand column of the table.

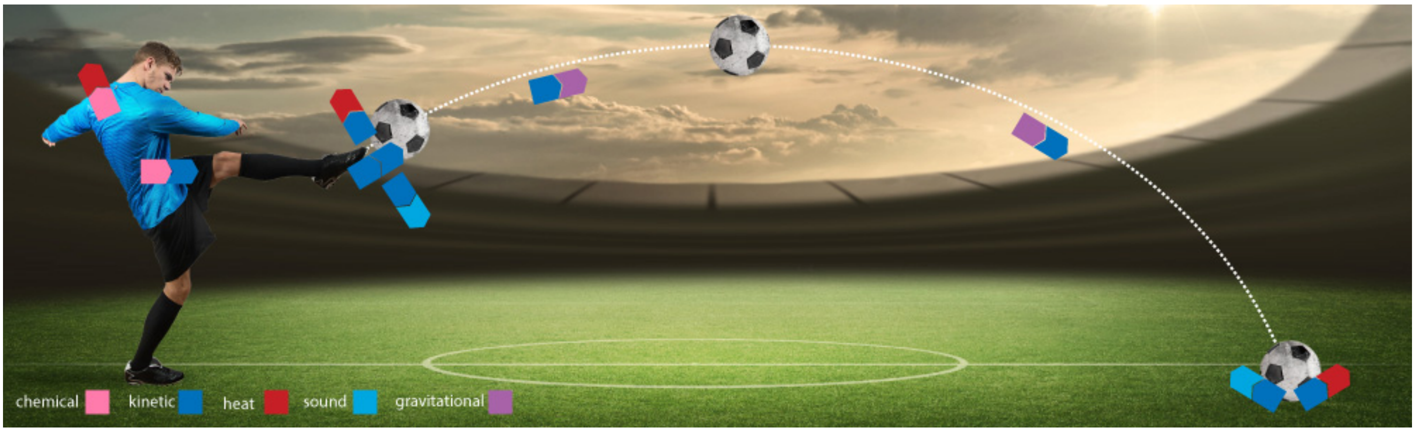
| | |
|---|---|
| Energy is the _________ to do work. | |
| Energy that is stored is known as _________ energy. | |
| The faster something is moving, the more _________ energy it has. | |
| The _________ something is, the more gravitational potential energy it has. | |
| The potential energy stored in petrol is an example of _________ energy. | |

## Energy transfer and transformation

Energy is often *transferred* from one object to another. When the soccer player shown below kicks a ball, the kinetic energy of his moving leg is transferred to the ball.

Energy can also be *transformed* – or converted – from one type to another. The player gets the kinetic energy he needs to move from the chemical energy in the food he eats. The ball's kinetic energy is transformed into gravitational potential energy as it rises through the air. This is converted back into kinetic energy as it falls.

In most energy transfers and transformations, a small amount of energy is lost to the surrounding air as heat and sound energy. In the case of kicking a ball, you can hear the sound easily enough but the amount of heat is too small for you to notice. On the other hand, the heat energy released by *metabolism* – the use of chemical energy by the body – becomes very noticeable as the game goes on.




Some of the energy transfers and transformations that take place when a soccer player kicks a ball.

## Question 2

**Analyze:** Take a close look at the energy transfers and transformations shown in the above diagram. Which type of energy is transformed into other types but is not itself produced?

- [ ] Kinetic energy
- [ ] Chemical energy
- [ ] Gravitational potential energy
- [ ] Heat energy

## Question 3

**Evaluate:** After bouncing on the ground, the ball will rise to a lower height than the maximum height shown.

This is because some of its kinetic energy is converted into heat and sound so it has less kinetic energy to convert back into gravitational potential energy.

- ○ True
- ○ False


Wile E Coyote and Roadrunner present: A Study of Energy

## Question 4

**Ponder:** If you ask for mercy from a falling rock, how likely is it that the rock will hear your plea and float back up into the sky?

- [ ] Fairly unlikely.
- [ ] More than fairly unlikely.
- [ ] It could happen. Rocks get sick of being predictable all the time.
- [ ] Rocks are stone deaf, so only if you have a very loud voice.

## Question 5

**Select:** Which of the following energy transformations do not take place in the video?

- [ ] Elastic potential to kinetic energy
- [ ] Electrical to chemical energy
- [ ] Gravitational potential to elastic potential energy
- [ ] Gravitational potential to kinetic energy

## The conservation of energy

Although energy can be transferred and transformed in all sorts of ways, it can never be created or destroyed. This basic principle is known as the *law of conservation of energy*.

Energy is measured in joules (J). One joule isn't much – it's roughly the amount of kinetic energy needed to lift a small apple to a height of one metre. This gives the apple one joule of gravitational potential energy, which is converted back into kinetic energy if you let it fall.

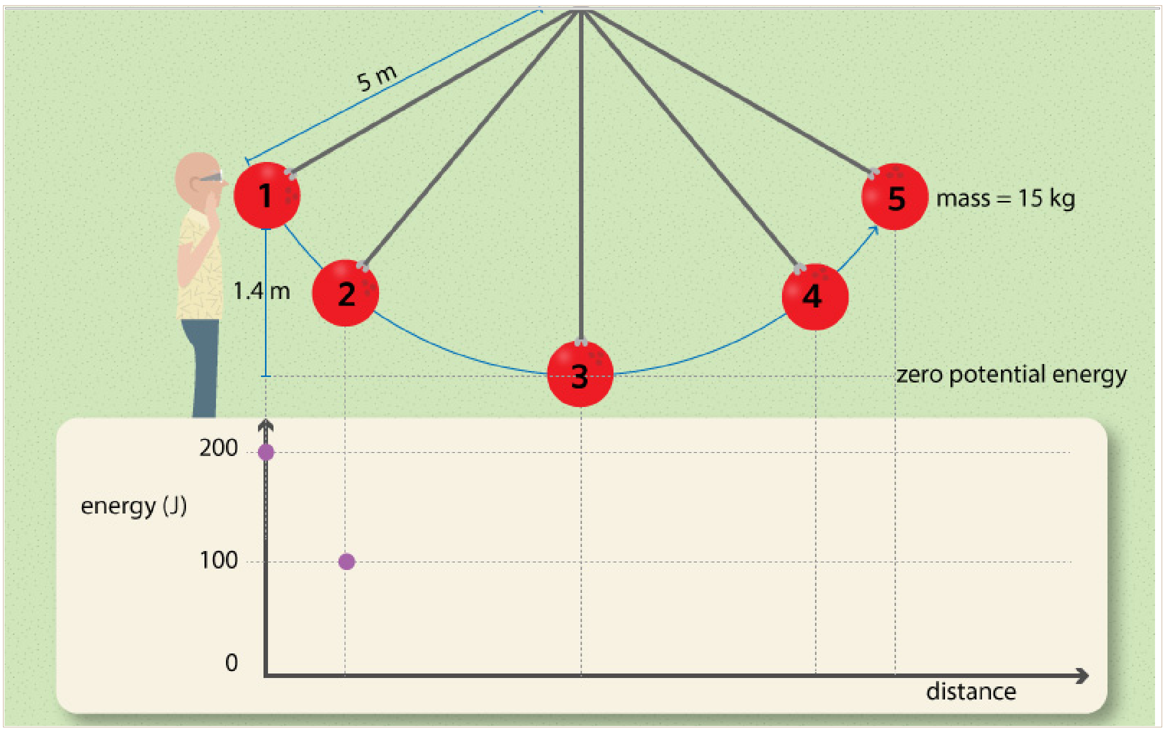
In this example, the combined amount of kinetic and gravitational potential energy remains constant, except that a tiny amount is transformed into heat energy and lost to the air. When these small and often hidden losses are taken into account, *total energy* is always conserved.


### Question 6

**Graph:** The first swing of the pendulum from the video is shown. Given that the pendulum's initial amount of gravitational potential energy is 200 J, use the pencil or line tools to plot on the same graph:

1. the potential energy as a purple line,
2. the kinetic energy as a blue line, and
3. the total mechanical energy as a green line.

*Hint: Use the dashed lines as guides to plot a few points before drawing each line – the first two potential energy points are provided. For the purposes of this question, assume that the ball rises to the same height at Point 5 as it had at Point 1.*



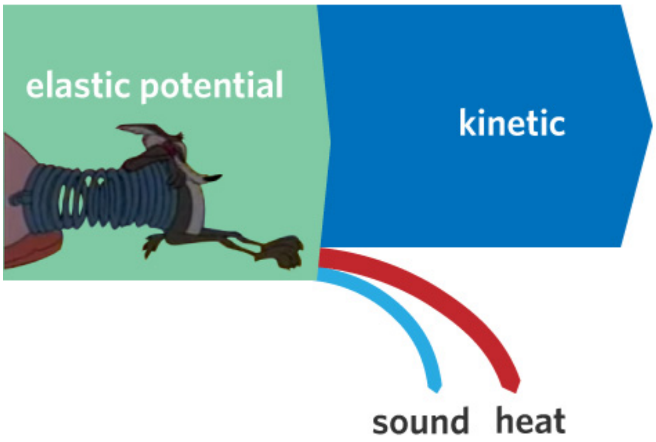
## Sankey diagrams

We can clearly represent energy transfers and transformations using *Sankey diagrams*. The flow of energy is shown as a large arrow pointing from left to right. If some of the energy is transformed into other types then the main arrow splits into a number of different arrows. There are two main rules:

- The thickness of each arrow indicates the amount of energy of that type.
- Because the total amount of energy is always conserved, the combined thickness of the "output" arrows must be equal to the combined thickness of the "input" arrows.

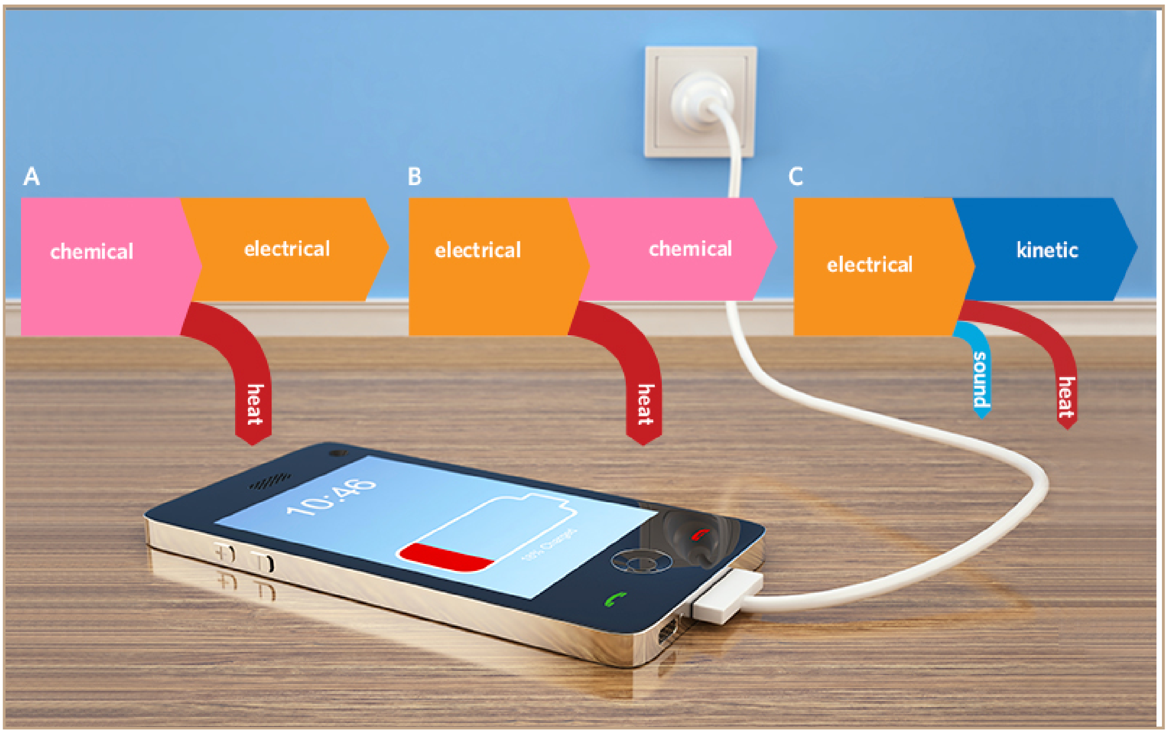
On the right is a Sankey diagram for the transfer of energy from the spring to the coyote. Before the transfer, all of the energy we're interested in is elastic potential energy in the spring.

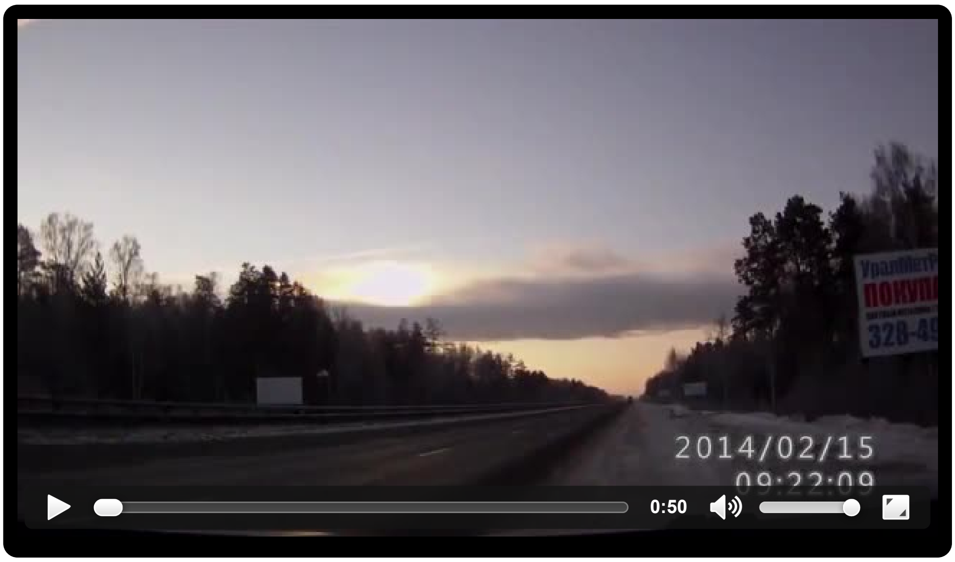
- Most of this is converted into kinetic energy in the coyote and the spring as they start to move.
- Some of the potential energy in the spring is transformed into heat energy – heat is usually produced whenever things move through air or rub against each other.
- A very small amount of the input energy is transformed into sound energy as the spring goes "TWANG-NG-NG".




### Question 7

**Decide:** Which of the three Sankey diagrams best represents the energy transfer and transformation as you recharge the battery in your phone? Draw a circle around the letter A, B or C.

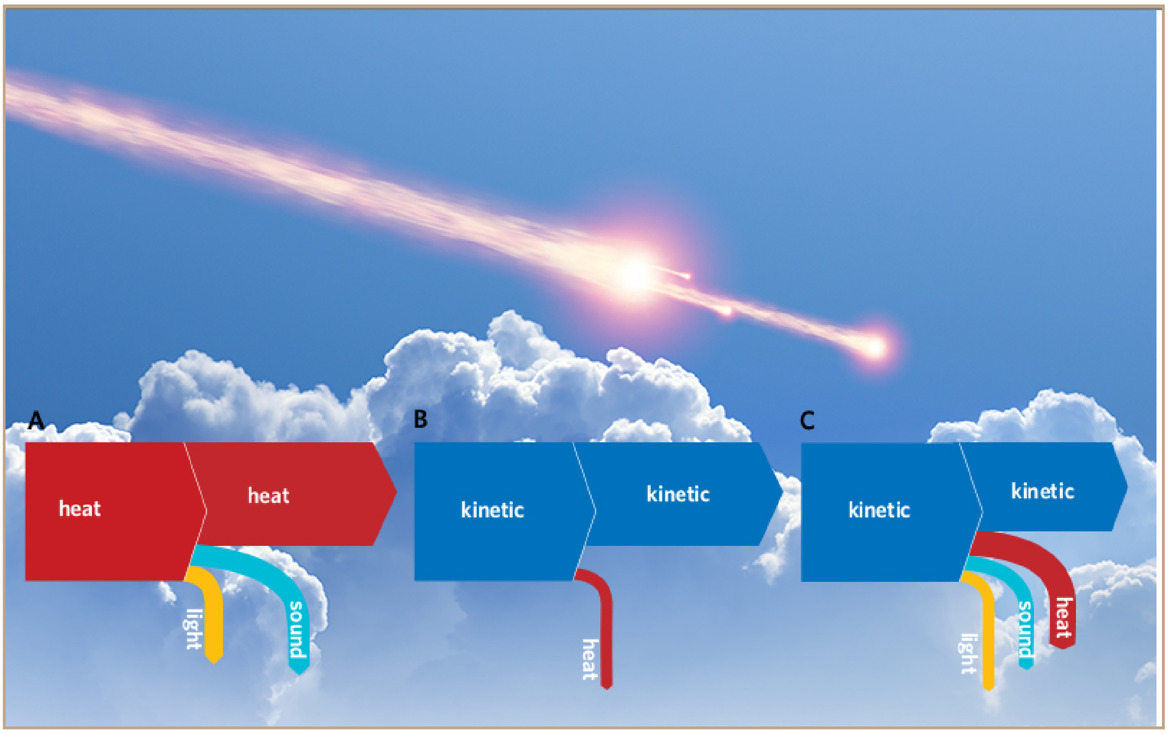





On February 15, 2013, a meteor fell over Chelyabinsk, Russia. It exploded in mid air, causing an air blast that damaged buildings and injured 1500 people.

## Question 8

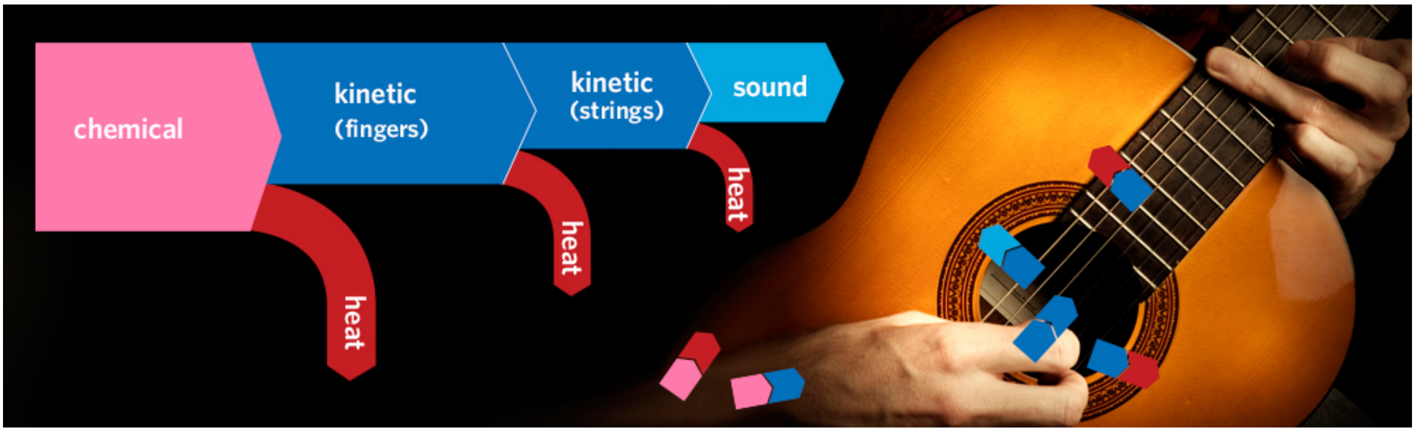
**Select:** Watch the video and decide which of the three Sankey diagrams best represents the energy transfer and transformation as the meteor falls through the atmosphere. Draw a circle around the letter A, B or C.




## Question 9

**Explain:** Explain what's wrong with Sankey diagram B in the above question. Why does it represent an impossible situation?

# Process: Energy transfer



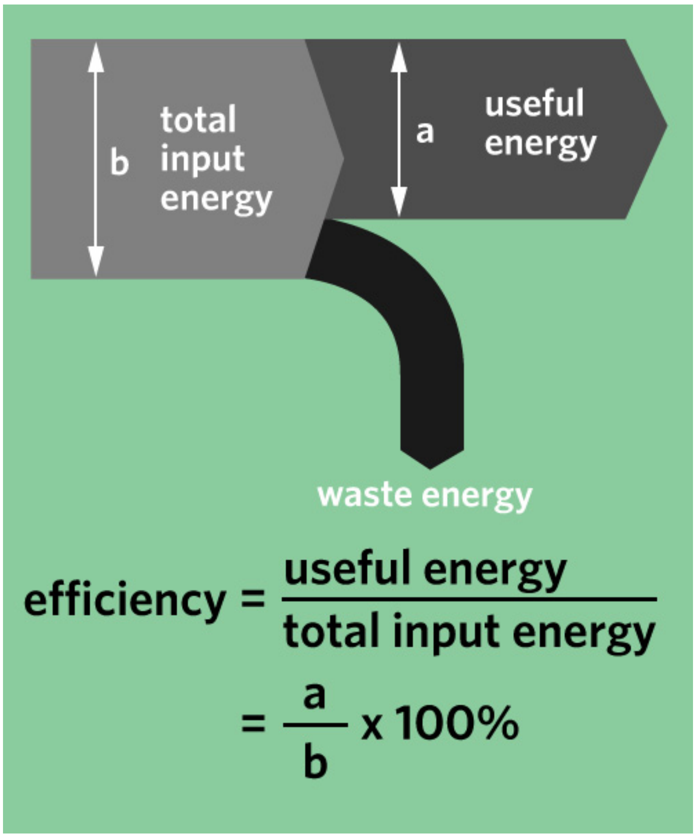

## Efficiency

Work requires energy. To play a guitar your body converts chemical energy into kinetic energy in your arms and fingers. Some of this is transferred to the strings and then transformed into sound.

But whenever we do work, only part of the energy we supply produces the result we want. We play guitars to create sound energy – music – but each step in playing one generates heat energy that serves no purpose.

- *Efficiency* is a measure of how much of the total energy supplied is *useful energy*. The rest is *waste energy*.

Sankey diagrams are especially good at representing efficiency. The useful energy is shown by the arrows that point to the right and the waste energy is shown by the arrows that curve downward.




### Question 1

**Select:** Which step in playing a guitar involves energy transfer *without* transformation?

- ☐ The generation of sound by the vibrating strings
- ☐ The plucking of the strings by the player's fingers
- ☐ The contraction of the muscles needed to move the player's fingers

### Question 2

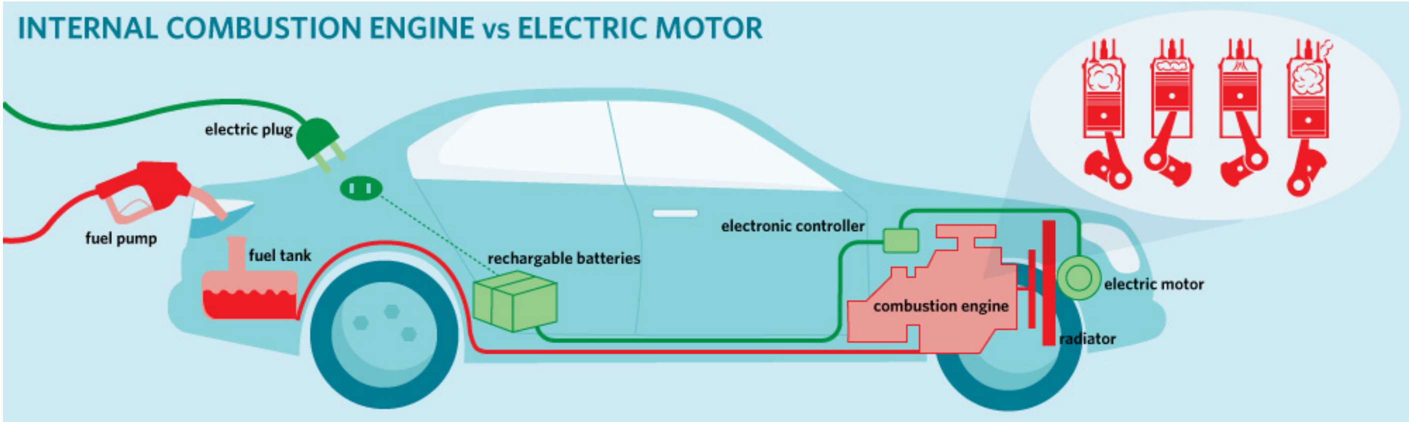
**Decide:** When someone uses a bow to shoot an arrow, which types of energy are useful and which types are waste?

- ☐ Useful: kinetic. Waste: elastic and heat.
- ☐ Useful: elastic and sound. Waste: heat and kinetic.
- ☐ Useful: chemical, kinetic and elastic. Waste: none.
- ☐ Useful: chemical, kinetic and elastic. Waste: heat and sound.

## Question 3

**Identify:** Name a machine, instrument or toy that's designed to make each of the following energy transformations.

| Energy transformation | Machine, instrument or toy |
|---|---|
| Electrical energy to heat energy | |
| Gravitational energy to kinetic energy | |
| Elastic energy to kinetic energy | |
| Kinetic energy to sound energy | |




The two main ways of powering a car – internal combustion engine and electric motor – are shown here in a hybrid electric vehicle, which uses both. The enlargement in the top right corner illustrates the four-stroke combustion cycle, in which the ignition of fuel causes rapid expansion of gas, driving the piston downwards in order to turn the car's wheels.

## Comparing the efficiency of cars

Cars with an *internal combustion engine* transform chemical energy into kinetic energy by igniting the petrol from the fuel tank – in a controlled way!

*Electric cars* transform chemical energy stored in a battery into electrical energy that runs the motor. The motor then transforms this electrical energy into kinetic energy.

We'll now use the equation introduced above:

$$efficiency = \frac{useful\ energy}{total\ input\ energy} \times 100\%$$

to compare the efficiency of petrol-fuelled and electric cars.

## Question 4

**Calculate:** For every 300 J of chemical energy supplied by the battery of one particular model of electric car, 45 J is lost as heat and the rest is transformed into electrical energy to power the motor.

How efficient is the transformation from chemical to electrical energy?

## Question 5

**Calculate:** Of the electrical energy supplied to the motor – as calculated in the previous question – 25.5 J is wasted as heat and the rest is transformed into kinetic energy.

How efficient is the transformation from electrical to kinetic energy?

## Question 6

**Draw:** On a piece of paper draw a Sankey diagram for the electric car's energy transformations. Draw neatly and remember to make the thickness of each arrow indicate the amount of energy it represents. Label all arrows with the type and amount of energy.

*Hint: it's easier to get the thicknesses of the arrows right if you use graph paper.*

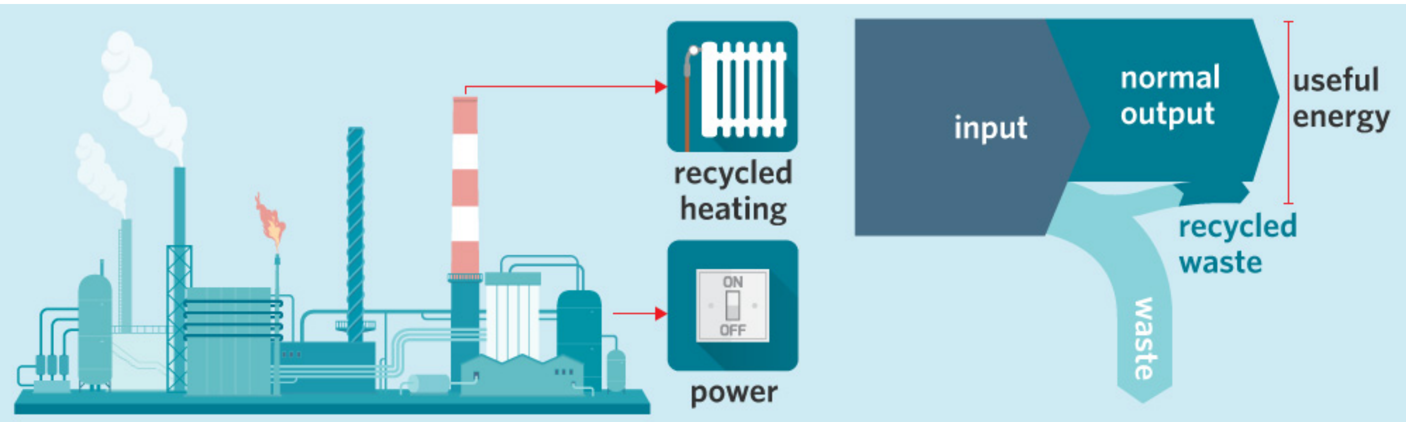
When you're finished, upload a photo of your diagram here:

Drag and drop file here to begin upload or

## Question 7

**Compare:** Although car models vary, typical chemical-to-kinetic energy efficiency for internal combustion engines is 15%.

Calculate the overall efficiency of the electric car examined above – given that out of 300 J of chemical energy in the battery a total of 70.5 J is wasted as heat – and then compare the overall energy efficiency of the two types of car.



## Making waste energy useful

As the world's energy demands increase, so does the pressure to use energy supplies wisely and make machines more efficient. The "star ratings" for appliances such as fridges and washing machines are one response.

Another way of saving energy is to capture some of the waste and convert it into useful energy. We can recycle energy just as we recycle paper and plastic. For example, when you turn food scraps into compost to feed the plants in your garden you make use of the chemical energy in the scraps, which would otherwise be wasted.

When conventional power plants convert the chemical energy in coal or gas into electrical energy they generate huge amounts of waste heat. In some countries some of this heat is used to heat people's houses. But as the *Cosmos Magazine* article describes, *thermoelectric* materials provide a promising way of converting waste heat directly into electricity.



### Question 8

**Imagine:** Suppose you're an inventor looking for a new way to use thermoelectric generators to turn waste heat into useful energy. Think of a source of waste heat and an electrical device that it could be used to power or recharge. How would you describe the benefits of your invention to potential users?

# Apply: Energy transfer

## Aim

To compare the bounce efficiencies of various balls and to analyze the energy transformations that take place.

## Materials

- 3 spherical balls of different kinds (e.g. tennis ball, baseball, cricket ball, golf ball, table tennis ball, squash ball, super ball)
- A metre ruler or tape measure
- A large (160 cm x 30 cm) sheet of paper
- Sticky tape
- A marking pen

## Method

1. Find a flat, hard surface next to a wall. Attach the sheet of paper to the wall with sticky tape so that one of the 30 cm ends touches the ground. Measure exactly 150 cm from the ground and draw a line at that point on the paper, labelled "150 cm".
2. Hold the first ball so that the top of the ball is exactly 150 cm above the ground. Drop the ball without applying any force and record how high it bounces by drawing a line on the paper at the point reached by the top of the ball. Label this line (e.g. "tennis 1" if it's the first trial with a tennis ball) and measure its height in centimetres using the ruler.
3. Repeat this procedure two more times with the same ball.
4. Repeat steps 2 and 3 for the other two balls.

## Results

### Question 1

**Calculate:** For each type of ball:

1. Enter your three measurements of bounce height and calculate the average.
2. Calculate the bounce efficiency by dividing the average bounce height by the height from which it was dropped, then multiplying by 100. Enter this value into the third column.

| Type of ball | Bounce height 1 (cm) | Bounce height 2 (cm) | Bounce height 3 (cm) | Average bounce height (cm) | Bounce efficiency (%) |
|---|---|---|---|---|---|
| | | | | | |
| | | | | | |
| | | | | | |

## Discussion

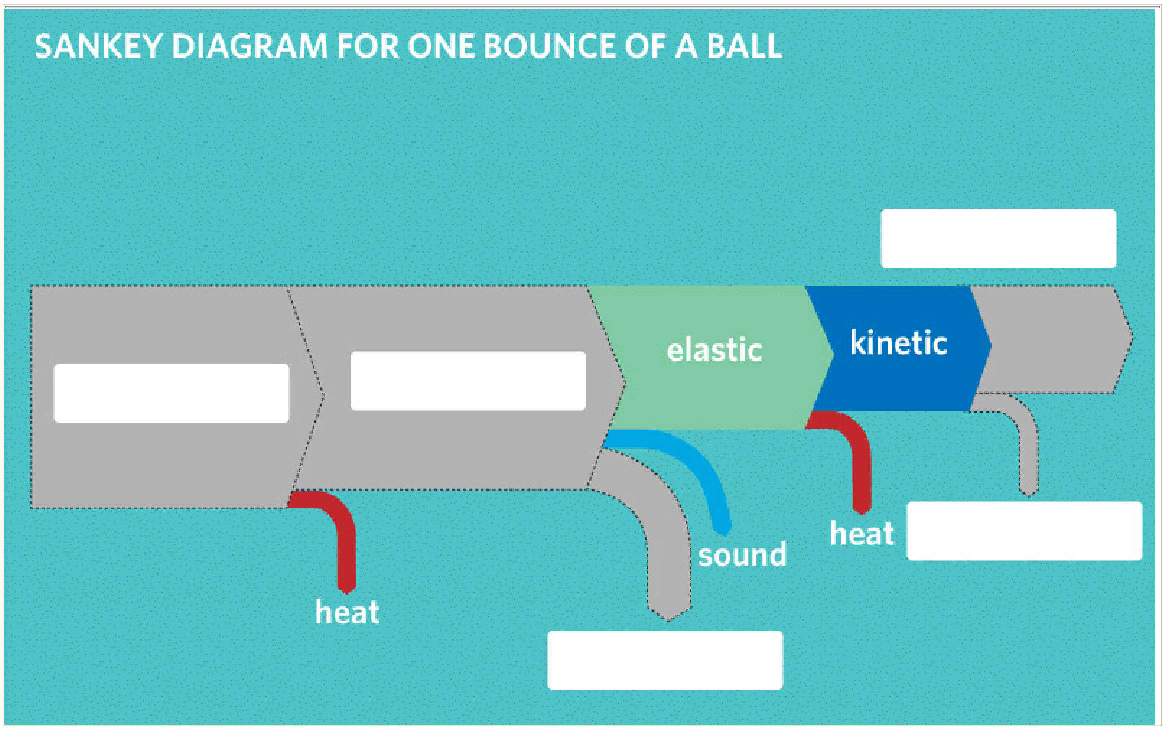
### Question 2

**Infer:** The bounce efficiency was calculated by dividing two *heights*. Explain why it can be used as a measure of energy efficiency.

*Hint: Remember which type of energy is directly related to height. Also, recall that energy efficiency is the useful energy divided by the total input energy. What is the useful energy in this case, given that we want the balls to bounce as high as possible?*

### Question 3

**Complete:** Fill in the blanks in the following Sankey diagram to show the energy transformations from when you dropped the ball to when it reached its bounce height.



### Question 4

**Explain:** Why don't the balls bounce back to their original heights? Do they violate the law of conservation of energy?

## Conclusion

### Question 5

**Conclude:** Write a short statement to address the aims of the experiment. What did you find out? How could the method be improved to gain more accurate results?

# Career: Energy transfer

Brought to you by Edith Cowan University

**At high school Corey Hewitt was an artist** – he even had a local reputation for his mural painting. So when he took a physics class in Year 12 he was surprised at how much he was drawn to such a challenging subject.

Corey thinks he was intrigued by the unanswered questions of science because he'd developed a love for problem-solving working on cars with his dad – a NASCAR mechanic. Now he uses those skills as a research scientist at the Wake Forest Center for Nanotechnology and Molecular Materials in North Carolina, US. There he mends microscopes and other equipment – when he isn't busy tackling the problem of how to make thermoelectric materials more efficient.

He came up with the idea behind Power Felt, a flexible, fabric-like material made up of layers of carbon nanotubes and plastic fibres. When exposed to a heat source – such as a car or even the human body – it generates electricity. Corey works on every aspect of the material, from creation through to performance testing. A big part of his job is to figure out how to make Power Felt as efficient as possible.

Corey finds the notion of capturing waste heat exciting – it's like energy scavenging, he says. You could even capture energy from the human body, which generates 100 W of power that is usually lost as heat. We need ways to power our high-tech world and thermoelectricity has a lot of untapped potential.

Cory loves doing TV and radio interviews and talking about the research done at the Wake Forest NanoCenter. But when he isn't busy doing that or heating things up in the lab, he enjoys hiking, rock climbing and restoring old cars – he's currently working on a 1963 Volkswagen Type 1.

## Question 1

**Think:** Inventions such as Power Felt show how advances in materials science open up the possibility that people in the future will use energy in very different ways to what we're used to. Why do you think it's important to change the way we use – and waste – energy?

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