Nanotechnology

At a glance

	Content summary	National Curriculum links	Activities
Lesson 1	Understanding the size of atoms and molecules Making graphene from graphite	Using prefixes; structure and bonding of graphene	**Activity A:** Introducing nanoscale science **Activity B:** Why is the nanoscale useful? **Activity C:** Making graphene
Lesson 2 (optional)	Presenting applications of nanotechnology to an audience	Explaining everyday and technological applications of science	Applications of nanotechnology

Background and National Curriculum links

These activities are designed for one or two lessons for Year 10-11 students on nanotechnology. Students learn about nanoscale science, make graphene and investigate applications. Two routes are suggested for using these resources depending on whether experiments are offered as teacher demonstrations or class practicals. This description follows Route 1.

Lesson 1

The basic principles of nanoscale science are introduced in the first lesson. This focuses on inviting students to consider the size of atoms and particles and how scientists have learned to 'see' atoms.

National Curriculum

- using prefixes and powers of ten for orders of magnitude (e.g. tera, giga, mega, kilo, centi, milli, micro and nano);
- structures, bonding and properties of diamond, graphite, fullerenes and graphene.

Lesson 2

In the second lesson, students research and present a range of applications of nanotechnology. This offers opportunities to carry out independent practical work.

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- explaining everyday and technological applications of science

Teacher subject knowledge

- understanding of atomic structure:
- some knowledge of the structure of graphene and its applications.

Cross-curricular links

This topic crosses science subject boundaries. The invention of the scanning tunnelling microscope (STM) and discovery of graphene both led to Nobel Prizes in physics for the scientists responsible. Nanotechnology is used to deliver transformational treatments in medicine. For example, drugs can be engineered precisely to fit patients' personal medical needs and delivered accurately to sites in the body using nanoscale techniques. Also in medicine, silver particles are used to develop coatings for medical equipment and within plasters for wounds, as silver has antimicrobial properties.

Nanotechnology has impacted materials science. For example, socks are less smelly when silver particles are incorporated into the sock fabric fibres. Nanoscale modifications to cotton and other fabrics have improved waterproofing properties. These adapted fabrics are useful in a variety of settings.

In electronics, applications of nanotechnology reduce the size of computers further, produce small, flexible and transparent displays, improve solar panels and enhance space telescopes.

Student background knowledge

Students need prior knowledge of atoms and atomic structure and some experience of chemical reactions. Basic knowledge of carbon allotropes, atomic structure and chemistry is useful.

Resources and timing

The activities as described require one or two 50 – 60 minute lessons. One lesson introduces nanoscale science and a simple method for making graphene.

To make the best use of a second lesson, this should be about 3 – 5 days later. This allows students to carry out independent research and prepare a presentation. The presentations are given in the second lesson.

Technical requirements

There are two ways of using this resource depending on students' abilities and availability of resources.

Route 1

Lesson 1 – complete all three activities, with B and C as teacher demonstrations. This will require about an hour. The lesson requires internet access as two short videos need to be shown. For homework, students must research applications of nanotechnology (see Extensions following Lesson 1).

Lesson 2 – involves students giving presentations either as a poster or a talk.
A whiteboard or similar equipment and / a display space is required (see Extensions following Lesson 1).

Route 2

Lesson 1 – Activity A: Introducing Nanoscale Science
Lesson 2 – Activity B: Why is the nanoscale useful? Activity C: Making Graphene.
This route allows extra time for students to make and test graphene in a class practical.
This route does not include student presentations. Students investigate research applications of nanotechnology as a homework task only.

Lesson 1

Activity A: Introducing nanoscale science

Introduce that atoms and molecules are measured in nanometres. This activity should help students understand the size of a nanometre.

1. A set of images and sizes of small objects is provided. Some we can see, others we can't. These can be a starting point for discussion. The limit of human vision is noted in the table. Students can add other examples, e.g.
   - 0.5 – 3 mm: Tip of a pin, grain of sand, dust specks, tiny red spider mites, holes or weaving patterns in fine material, threads of fabric, hair or fur.
   - About 3 mm – 5 mm: Insect larvae, creases in skin, fingerprints, coarse salt crystals (sold as "sea salt"), granulated sugar crystal, drop of liquid from a pipette, eyelashes.
   - About 5 mm – 1 cm little finger/toenail, drawing pin head, contact lens, button, a pill or medicine tablet, SIM card, microchip.
   - 0.1 mm details of salt crystals, dust mites, details on a microchip.
   - 10 – 100 μm (micrometres, or microns) cells, some bacteria.
   - 0.3 – 1 μm some bacteria, viruses, DNA.
   - 1 nm (nanometre) molecules, atoms.
   - 1 pm (picometre) atomic nuclei.
   - 0.1 fm (femtometre) the matter in a proton.

2. Ask why we think of these as 'small', for example:
   - The sizes of these objects are close or beyond the limit of human vision.
   - We see these objects as small relative to other items.

3. The scale we are interested in is the nanometre scale (nanoscale). This is the size of atoms and molecules. A nanometre is 1 x 10^{-9} m, roughly 1 nm per atom. Ask students to calculate the sizes of the 'small' items listed in nanometres. This has been done for the images provided.
   - There are 10,000,000 nanometres in 1 cm.
   - There are 1,000,000 nanometres in 1 mm.

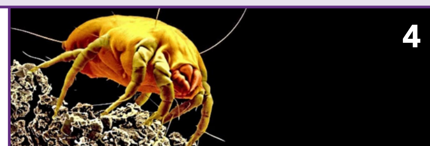
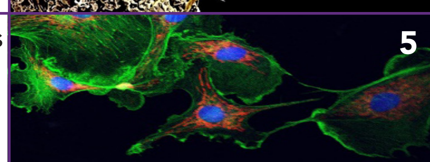
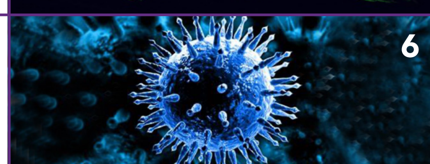
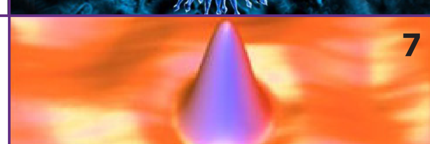
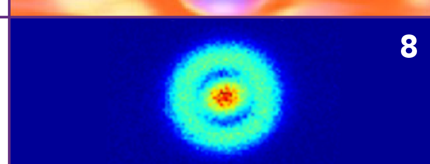
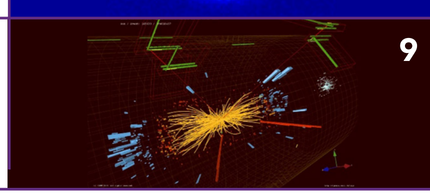
4. Here are some suggestions to help develop students' thinking about the size of atoms.
   - A visual image. For example, measure 25 g from a 1 kg bag of rice. Ask students to estimate the number of grains present. The answer is approximately 1000 grains. They will almost certainly under-estimate this. Scaling up, there are about 40,000 grains in 1 kg; so, about 25 kg are needed for 1 million grains. Now try to imagine 1 million atoms. This is roughly equivalent to 1 mm.
   - A 20 cm hand span is 20,000,000 nm.
   - An 8 cm long paper clip is 8,000,000 nm long.
   - A 5p piece is about 1,800,000 nm in diameter.

5. Atoms can be seen through a scanning tunnelling microscope (STM). Images of atoms are provided. The images are coloured to distinguish types of atom. Atoms are not coloured. The atoms appear as spikes not round balls, which is our usual mental image. This is because of the way the STM works.

6. Show the video 'The Boy and His Atom'. A link is: [http://www.research.ibm.com/articles/madewithatoms.shtml.](http://www.research.ibm.com/articles/madewithatoms.shtml)

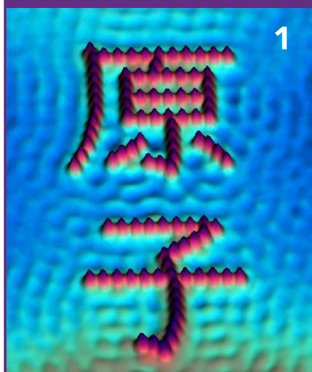
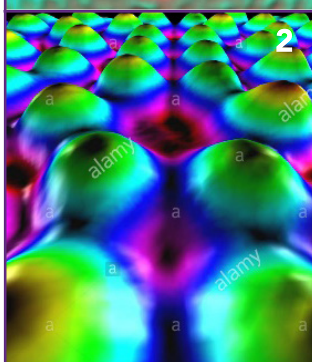
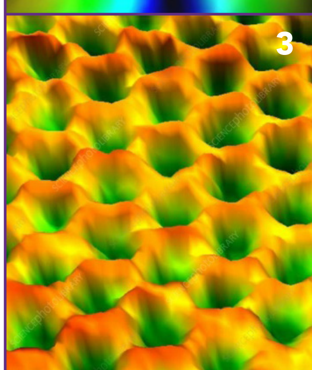
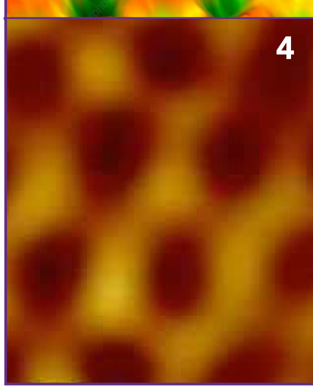
   The STM was developed in 1981 by Gerd Binnig and Heinrich Rohrer while working at IBM Zurich Research Laboratories in Switzerland. They won the 1986 Nobel Prize for Physics. Since then, IBM scientists have made the 'World's Smallest Movie' using an STM. This animated sequence lasting about 90 seconds was made by moving atoms to form a series of images, then running them as an animation. The movie has been accredited by Guinness World Records as the smallest in the world.

Lesson 1 Activity A Introducing Nanoscale Completed version

Size	Object	Image	Size in atoms (nm)
Objects our eyes can see			
0.5 – 4 mm	Sand grain	 1	500,000 – 4,000,000
3 – 5 mm	Sugar crystal	 2	3 – 5,000,000
5 mm – 1 cm	SIM card	 3	5 – 10,000,000
Objects our eyes can't see			
0.1 mm	Dust mite	 4	100,000
10 – 100 μm (micrometres, or microns)	Cells – these animal cells have been coloured to highlight their features	 5	10,000 – 100,000nm
0.3 – 1 μm	Viruses, DNA - this is an image of a flu virus	 6	300 - 1000nm
1 nm (nanometre)	Molecules, atoms – the single purple spike is an atom	 7	1 nm
1 pm (picometre)	Atomic nuclei – the red / yellow area is a hydrogen nucleus	 8	0.001nm
0.1 fm (femtometre)	The matter in a proton – there is no direct image but this shows results of high energy collisions between particles	 9	0.000001nm

1. image of a sand grain - Bing images
2. image of a sugar crystal - Bing images
3. image of a SIM card - Bing images
4. dustmite6.jpg (980×735) (killdustmite.com)
5. 1200-452475747-cell-cytoskeleton.jpg (1200×1200) (pixfeeds.com)
6. photo of a virus - Bing images
7. photo of an atom STM - Bing images
8. Atomic Single Atom Under Microscope - Bing images
9. image of matter in a proton - Bing images

STM images of atoms

STM images of atoms	
 1	These Kanji characters mean 'atom'. Separately, the characters mean 'original' and 'child' in Japanese and Chinese. The image shows iron atoms arranged on a copper surface.
 2	This is an image of a silicon chip.
 3	This is an image of graphene.
 4	This is an image of plumbene, graphene's 'cousin'. Plumbene is made up of a single layer of lead atoms.

1. stm images of atoms - Bing images
2. silicon-atoms-of-a-silicon-chip-imaged-with-a-scanning-tunneling-microscope-b714ht.jpg (1300×1065) (alamy.com)
3. stm images of graphene - Bing images
4. stm images of atoms - Bing images

Lesson 1 Activity B: Why is the nanoscale useful?

On the nanoscale, substances have different properties to those we see. Carrying out experiments on a nanoscale is leading to new discoveries. If scientists can move atoms individually, this means we can be really precise about the chemical reactions we want to occur.

This demonstration illustrates how behaviour changes when we change the surface area of a reactant to very small scale.

For the soluble tablet demonstration:

- 2 x 250 cm^3 beakers
- 2 x soluble tablets, e.g. vitamin C, Alka seltzer
- Water
- Ruler
- Pestle and mortar
- Stopwatch

1. Measure the diameter of a soluble tablet in cm. Convert this to nanometres. Use the discussion in 'Introducing nanoscale science' (i.e. roughly 1 atom = 1 nm) to work out how many atoms are aligned along the diameter of the tablet.
2. Drop the tablet into a beaker of water. Time how long it takes for the tablet to dissolve completely. Observe what happens. Bubbles of gas are produced gently. The beaker may become slightly warm.
3. Repeat the experiment, but with a powdered tablet. Estimate the size of the powder grains. Convert this to nanometres. How many particles are in each powder grain? Remember that 1 mm = 1,000,000 nm. How will using a powder affect the reaction?
4. Add the powdered tablet to a beaker of water. The reaction will be much more dramatic, with gas produced very rapidly. The beaker may become hot. The time taken to dissolve the tablet will be much shorter.
5. Discuss why the two reactions are the same, yet different. Students should understand that the surface area of the powdered tablet is much greater than that of the whole, single tablet. Using a powder increases the rate of reaction by providing many more opportunities for the particles of reactants to meet. For the powder, change in temperature is more dramatic and easier to measure. The demonstration shows that the chemical reaction changes character when the tablet is powdered.
6. Discuss what might happen if we could add each tablet particle separately. Why and how might this be useful? This would allow precise control of the reaction. We could add as many or as few particles of powder as we wanted to.

This three-minute video is called 'There is plenty of room at the bottom'. It is about physicist

Richard Feynman's ideas about nanotechnology – which he was thinking about before we could even 'see' atoms using STMs. http://www.youtube.com/watch?v=eKj5lAmy9Wk.

Lesson 1

Activity C: Making graphene

Introduce graphene. Graphene is one-atom thick sheet of carbon atoms arranged in a honeycomb-style pattern of interlinked hexagons. An image is shown in the 'Images of atoms' table above.

Graphene was first isolated by Professor Sir Andre Geim and Professor Sir Kostya Novoselov at the University of Manchester in 2004.

For the graphene demonstration:

This can be a class experiment or teacher demonstration.

- Plastic tweezers with a pointed tip
- Sticky tape – allow several 10 cm pieces per student group
- A piece of white card about 10 cm x 10 cm
- Soft drawing pencil (6B is best)
- Pencil sharpener
- Pencil eraser
- Battery and bulb circuit comprising a 9 V battery, 9 V snap connectors, 5 mm LED bulb, 330 Ohm resistor, two insulated leads with alligator clips at the ends (a buzzer can be used instead of an LED bulb)
- Molymod® or similar to make a graphene sheet – this will be most effective if many hexagonal rings are combined into one large model
- *Optional:* Flakes of graphite

To make graphene:

1. Take a piece of sticky tape about 10 cm long.
2. Keeping hold of the ends, fold the tape so that the centre section can be re-opened by gently pulling the two ends as tabs.
3. If graphite flakes are available, pick up ONE flake of graphite with the tweezers, and place it in the centre fold of the sticky side of the tape OR If a 6B pencil is available, hold the tape sticky side up. Draw a short line or dot in the centre fold of the tape with the pencil.
4. Fold the tape in half over the graphite flake or pencil mark, rub for a few seconds, then peel it apart.
5. Repeat the folding, rubbing and peeling back several more times, placing a clean part of the tape over the graphite section. This will spread the graphite thinly along the tape.

6. Stick the piece of tape onto the top half of the white card.

   - What do you see?

There should be faint smudges of graphite on the sticky side of the tape. The folding and unsticking process separates layers of graphite in the flake / pencil mark. Some layers produced may be one atom thick – but remember we cannot see these!

- How could we 'see' exactly what layers are present?

Revisit the 'Introducing Nanoscale Science' activity to consider the depth of the layers. Why can't we tell for certain what the thickness is? If we can still see the graphite, what does this tell us?

Our eyes cannot see at nm levels.

We can see the length and width of the graphite layers.

- Measure the length and width of the graphene pieces under the tape in nanometres. How many atoms of carbon are in the graphene pieces?

This repeats the experiment for which Geim and Novoselov won the 2010 Nobel Prize for Physics! But they also showed how to measure the thickness of the graphene and studied its properties.

- Put graphene in an electric circuit

Use the 6B pencil to colour a strip measuring 1 x 2 cm on the lower half of the piece of card. Make sure the strip is dense, so no card is visible along its length. This is a strip of graphite.

Set up an electric circuit using the LED bulb/buzzer, resistor, battery and leads.

Complete the circuit by touching the two alligator clips against the graphite strip, one at each end. The bulb should light (or the buzzer sound).

Take a second piece of tape and rub this over the strip to lift graphite from the card. Alternatively, use a pencil eraser to steadily remove graphite from the strip. Test the conductivity each time. How far can you go? Try to get the thinnest possible graphite layer that still conducts electricity. This may be graphene. Discuss how we might know this for certain.

- Build a model of graphene using a Molymod® kit (or similar). Use the model to work out why and how graphene conducts electricity.

Graphene is made from carbon atoms. Each carbon atom contributes one electron to a molecular orbital. Electrons in the molecular orbital are free to move when an electric current is passed through the graphene.

- What properties does graphene have?

Graphene makes a flexible sheet; can be infinitely long / wide; is always one atom thick, so has a consistent depth.

Graphene is flexible, strong, nearly transparent, conducts electricity.

Graphene can be rolled into carbon nanotubes to form one-atom layer wires with walls that are one atom thick.

Graphene can be used in transparent electronic displays, tiny super-fast computer chips, drug delivery systems, solar energy production, making DNA and anti-corrosion coatings and paints, and many other applications.

Extensions

A Nanotechnology Conference

Students can research nanotechnology applications such as:

a. Drug delivery;
b. Fabrics – new materials with specific properties built into the fibres, e.g. smell-resistant, waterproof, colour-changing, heat resistance;
c. Engineering – coatings and paints for different structures, solar panels, liquid crystals ;
d. Personalised medicine – designing drugs for individual patients;
e. Electronics – smaller computers and microchips.

Working in pairs / small groups, students investigate one application and prepare a presentation. The presentations could be arranged as a 'Nanotechnology Conference' imitating a scientific conference. Students can choose if they want to present a poster or give an oral presentation.

If students make a poster, this needs to summarise what they found out. Professional posters can be printed at low cost. Students stand by their posters, talk briefly about them and answer questions.

If students give a talk, this needs to be for about 10 minutes, with time for questions.

A guest speaker could be invited, such as a nanotechnology researcher working in industry or a university, or a STEM Ambassador.

Modelling nanotubes

Build a model of a carbon nanotube using modelling balloons. This creates a large sculpture that can be hung from the ceiling of a classroom / laboratory or even a school hall for an open event, or to complement a Nanotechnology Conference. The task can involve the whole class in construction. Besides modelling balloons (those used by balloon artists), the structure requires some supporting tubing. Full instructions are available on the attached resource sheet.

Industry / research laboratory visit

Visit a research laboratory or company using and/or developing nanotechnology applications. Use this as an opportunity to develop students' understanding and appreciation of the cutting edge of scientific knowledge of the field. What are the ‘unknowns’ that the researchers are investigating?

Resources

Nanotechnology is a rapidly developing field, so website content can be expected to change fairly rapidly over time.

The National Informal STEM Education Network in the US website is: https://www.nisenet.org/ .

A pdf of resources for a set of activities on nanotechnology is available at: https://www.nisenet.org/sites/default/files/catalog/uploads/8416/high_school_nanocamp.pdf.

The website ScienceNotes also has good activities and supporting information, for example: https://sciencenotes.org/make-graphene-in-this-simple-experiment/.

The Royal Society of Chemistry has a set of nanotechnology activities at: http://www.rsc.org/learn-chemistry/resourceres00001933nanotechnology?cmpid=CMP00006191#!cmpid=CMP00006193. This includes information about silver particles and smelly socks.

www.trynano.org has some good experiments.

Student sheets

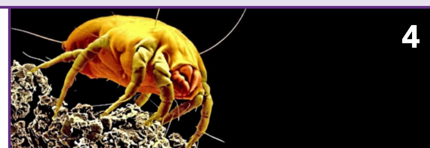
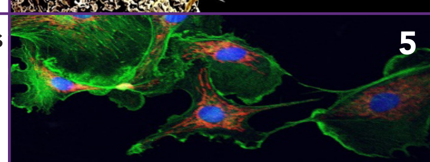
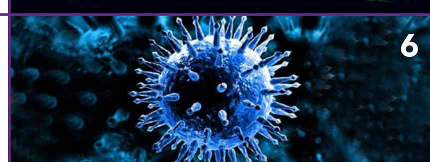
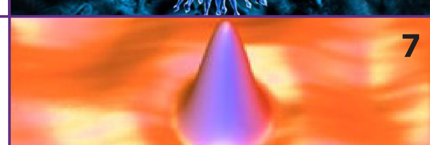
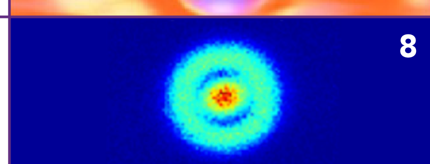
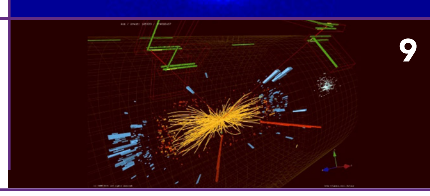
Lesson 1 Activity A Introducing Nanoscale

1. Look at the images in the table below. What other objects have these sizes? Add their names to the table under 'object'. Mark an 'X' on the table next to the smallest image that we can see with the human eye.
2. Why do we think of these as 'small'? What does 'small' mean?
3. Using the scale shown, work out the size of these objects in atoms.

   1 atom is 1 nm

   There are 10,000,000 nanometres in 1 cm.
   There are 1,000,000 nanometres in 1 mm.

4. Find out how many atoms are in:
   a. your handspan (the distance from the tip of your little finger to the tip of your thumb);
   b. a small paper clip – a piece of metal 8cm long;
   c. a small coin, e.g. a 5p piece 1.8cm in diameter.

Size	Object	Image	Size in atoms (nm)
Objects our eyes can see			
0.5 – 4 mm	Sand grain		
3 – 5 mm	Sugar crystal		
5 mm – 1 cm	SIM card		
Objects our eyes can't see			
0.1 mm	Dust mite		
10 – 100 μm (micrometres, or microns)	Cells – these animal cells have been coloured to highlight their features		
0.3 – 1 μm	Viruses, DNA - this is an image of a flu virus		
1 nm (nanometre)	Molecules, atoms – the single purple spike is an atom		
1 pm (picometre)	Atomic nuclei – the red / yellow area is a hydrogen nucleus		
0.1 fm (femtometre)	The matter in a proton – there is no direct image but this shows results of high energy collisions between particles		

1. image of a sand grain - Bing images
2. image of a sugar crystal - Bing images
3. image of a SIM card - Bing images
4. dustmite6.jpg (980×735) (killdustmite.com)
5. 1200-452475747-cell-cytoskeleton.jpg (1200×1200) (pixfeeds.com)
6. photo of a virus - Bing images
7. photo of an atom STM - Bing images
8. Atomic Single Atom Under Microscope - Bing images
9. image of matter in a proton - Bing images

Lesson 1 / 2

Activity B: Why is nanoscale useful?

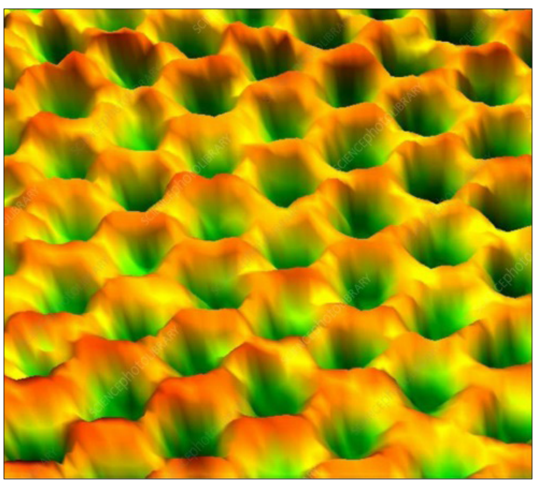
Watch the demonstration.

Write down:

- How many atoms are in the diameter of the tablet.
- How many atoms are in one grain of powdered tablet.
- What do you notice about the two reactions?
- Why does the reaction change?
- What does this tell us about doing reactions using very small particles?

Activity C: Making graphene

Here is an image of graphene:



stm images of graphene - Bing images

Write down what you know about graphene.

To make graphene:

1. Take a piece of sticky tape about 10 cm long.
2. Keeping hold of the ends, fold the tape so that the centre section can be re-opened by gently pulling the two ends as tabs.
3. If graphite flakes are available, pick up ONE flake of graphite with the tweezers, and place it in the centre fold of the sticky side of the tape
4. OR If a 6B pencil is available, hold the tape sticky side up. Draw a short line or dot in the centre fold of the tape with the pencil.
5. Fold the tape in half over the graphite flake or pencil mark, rub for a few seconds, then peel it apart.

6. Repeat the folding, rubbing and peeling back several more times, placing a clean part of the tape over the graphite section. This will spread the graphite thinly along the tape.
7. Stick the piece of tape onto the top half of the white card.
8. How would you know if you have got a piece of graphene?

To test if graphene conducts electricity

1. Use the 6B pencil to colour a strip measuring 1 x 2 cm on the lower half of the piece of card. Make sure the strip is dense, so no card is visible along its length. This is a strip of graphite.
2. Set up an electric circuit using the LED bulb/buzzer, resistor, battery and leads.
3. Complete the circuit by touching the two alligator clips against the graphite strip, one at each end. The bulb should light (or the buzzer sound).
4. Take a second piece of tape and rub this over the strip to lift graphite from the card. Or, use a pencil eraser to steadily remove graphite from the strip. Test the conductivity each time. How far can you go? Try to get the thinnest possible graphite layer that still conducts electricity. This may be graphene.

What properties does graphite have?