BBC Bitesize - Chemistry

Episode 6 – Allotropes of carbon

SUNAYANA: I'm Dr Sunayana Bhargava, a scientist and poet.

TULELA: And I'm Tulela Pea, a science communicator and podcaster.

SUNAYANA: And this is Bitesize Chemistry.

TULELA: This is episode six in an eight-part series on bonding, structure and properties. In this episode, we're going to look at allotropes of carbon. First, there's diamond – super hard and sparkly, basically atomic level bling.

SUNAYANA: There's also graphite, its laid-back cousin.

TULELA: And then graphene? Strong and conductive which is revolutionising electronics. All allotropes of carbon.

SUNAYANA: As always, it might be handy to write some notes or diagrams along the way.

TULELA: Let's do it.

SUNAYANA: In previous episodes, we looked at covalent bonds, how molecules and compounds share their electrons to complete their outer shell.

TULELA: And we also looked at how in giant covalent structures all the atoms are held together by covalent bonds and are arranged in giant regular lattices. So these are extremely strong structures.

SUNAYANA: Carbon is a wonderful example of an element that forms giant covalent structures. There are different forms of these structures called allotropes, depending on how the atoms are bonded covalently. First up, diamond.

TULELA: In diamond, each carbon atom contributes one electron to a shared pair with each of its four neighbouring carbon atoms. The shared electrons give rise to a tetrahedral arrangement, where each carbon atom is at the centre of the tetrahedron.

SUNAYANA: Which is a shape of a pyramid with a triangular base.

TULELA: The result is a vast network of interconnected carbon atoms, forming a rigid and robust structure where each carbon atom forms 4 covalent bonds with other carbon atoms.

SUNAYANA: So the covalent bonds in diamond are exceptionally strong, and so diamond is very hard and has a high melting point but it doesn't conduct electricity because it doesn't have any delocalised electrons or ions.

TULELA: i.e. no freely moving charges.

SUNAYANA: Exactly. Next up, graphite.

TULELA: In graphite, each carbon atom is covalently bonded to three of its neighbours. This creates a pattern of atoms arranged in hexagonal sheets, a bit like a honeycomb. The intermolecular forces between the sheets are fairly weak, so that they can slip over each other easily and so graphite is much softer than diamond and this is why it is often uses as a lubricant or in pencils because the layers rub off onto paper.

SUNAYANA: But even though the forces between those sheets are weak, the covalent bonds between atoms are strong, so graphite also has a high melting and boiling point.

TULELA: Right.

SUNAYANA: So in diamond, carbon shares four electrons with neighbours, in graphite it shares only three. What of that other one?

TULELA: Aha! This spare electron is delocalised between the layers which means, Sunayana?

SUNAYANA: That graphite conducts electricity.

TULELA: Exactly, it does. And this why you'll often see graphite electrodes being used in electrical circuits. So if graphite are layers of those hexagonal patterns of carbon atoms and those layers are held together by weak forces, then graphene is simply one layer of graphite.

SUNAYANA: So like a two-dimensional very, very thin form of graphite.

TULELA: Yeah, really thin – just one atom thick. It was invented in 2004 by two scientists in the University of Manchester and you'll never guess how they did it.

SUNAYANA: Some amazing high-tech really expensive laboratory equipment with powerful lasers?

TULELA: Nope, sticky tape.

SUNAYANA: You're kidding.

TULELA: They used sticky tape to remove the flakes from a lump of graphite. Then used more sticky tape to make the flakes ever thinner, and then they kept going until they made flakes just one atom thick – and, bingo! Graphene.

SUNAYANA: What a beautifully simple but amazing invention. What about some of its properties?

TULELA: Well, despite its single-atom thickness, graphene is incredibly strong in fact it's one of the strongest materials known. It's ten times stronger than steel. Added to that, it is transparent and an excellent conductor of heat and electricity because it has delocalised electrons.

SUNAYANA: So that's graphene. Next up are a whole family of hollow-shaped carbon structures called fullerenes. Their structures are based on hexagonal rings of carbon atoms joined by covalent bonds, although some rings can have five carbon atoms and others have seven atoms. One example of a fullerene is called a carbon nanotube.

TULELA: You can imagine a carbon nanotube as a layer of graphene rolled into a cylinder to create a tube. And because nanotubes share all the properties of graphene, they conduct electricity and heat well. And although they are very, very, light, they are also very, very strong.

They have a very high length to diameter ratio and can withstand a lot of tension without breaking. And all these properties make nanotubes useful for nanotechnology, electronics and specialised materials. You might even have a tennis racket or hockey stick which uses carbon nanotube technology.

SUNAYANA: Whilst you're talking about sport, let's finish with the first fullerenes to be discovered - my favourite allotrope of carbon – buckminsterfullerene.

TULELA: Say it again.

SUNAYANA: Buckminsterfullerene – just rolls off the tongue, doesn't it? I want you to imagine a football made up of 20 hexagon patches and 12 pentagon ones all stitched together. Now shrink that down to an atomic level. At the intersection where three of those shapes meet we're going to pop a carbon atom. We'll find that there will be a total of sixty atoms all covalently bonded together across this ball, C_{60}, otherwise known as 'buckminsterfullerene' or because of its shape, nicknamed a 'bucky-ball'.

TULELA: So why's it your favourite carbon allotrope?

SUNAYANA: Well, like graphene it was discovered only relatively recently, in the 1980s in fact, by a chemist at the University of Sussex - and that's where I studied.

TULELA: And also nice that both buckminsterfullerene and graphene demonstrate that chemistry is a living breathing subject where we are continuously making new discoveries and creating new materials with amazing properties.

SUNAYANA: Quiz time! Three questions about allotropes, five seconds to write down the answers. Here goes.

TULELA: Question 1. In diamond, how many covalent bonds does each carbon atom form with its neighbouring carbon atoms?

SUNAYANA: Answer – 4.

TULELA: Question 2: Why is graphite able to conduct electricity?

SUNAYANA: Because of its delocalised electrons between the hexagonal layers.

TULELA: And question 3 – what's the name of the carbon allotrope with sixty carbon atoms arranged in a football shape?

SUNAYANA: Buckminsterfullerene.

TULELA: Yep, exactly that.

SUNAYANA: There's more chemistry on the Bitesize website, where you can also find diagrams of the structures of those fascinating carbon allotropes.

SUNAYANA: Carbon allotrope summary, anyone?

TULELA: Start us off.

SUNAYANA: Diamonds - in diamond, each carbon atom forms four covalent bonds with other carbon atoms, so diamond is very hard.

TULELA: Graphite. Each carbon atom forms three covalent bonds with three other carbon atoms, forming layers of hexagonal rings - one electron from each carbon atom is delocalised.

SUNAYANA: Graphene is a single layer of graphite and has properties that make it useful in electronics and composites.

TULELA: Fullerenes are molecules of carbon atoms with hollow shapes.

SUNAYANA: And the first fullerene to be discovered was Buckminsterfullerene shaped like a sphere.

TULELA: In the next episode, we'll be looking at states of matter.

SUNAYANA: Solids, liquids and gases.

TULELA: And what it takes to go from one state to another.

SUNAYANA: To hear more, search 'Bitesize Chemistry' on BBC Sounds.

TULELA: Thanks for listening.

SUNAYANA: Bye.

BOTH: Buckminsterfullerene.