Sizes of particles and their properties

4.2.4.1 · Bonding, structure and the properties of matter · revision notes

What nanoparticles are, how their size compares with atoms, fine particles and coarse particles, and why their very high surface area to volume ratio gives them different properties. Expect size comparisons in standard form and surface area to volume calculations for cubes. Nanoscience is in GCSE Chemistry only, not in Combined Science.

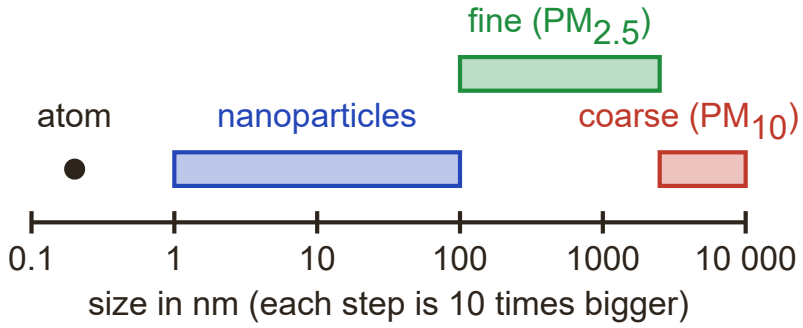
Key facts

- Nanoparticles: 1–100 nm across (a few hundred atoms)
- Fine particles, $PM_{2.5}$: 100–2500 nm (1×10^{-7} m to 2.5×10^{-6} m)
- Radius of an atom ≈ 0.1 nm = 1×10^{-10} m
- Side 10 times smaller → surface area to volume ratio 10 times bigger
- $1 \text{ nm} = 1 \times 10^{-9}$ m
- Coarse particles, PM_{10} (dust): 2.5×10^{-6} m to 1×10^{-5} m
- Cube: surface area = $6L^2$, volume = L^3, surface area ÷ volume = 6 ÷ L
- High surface area to volume ratio → different properties from bulk; smaller quantities needed

Notes

Nanoscience and particle sizes

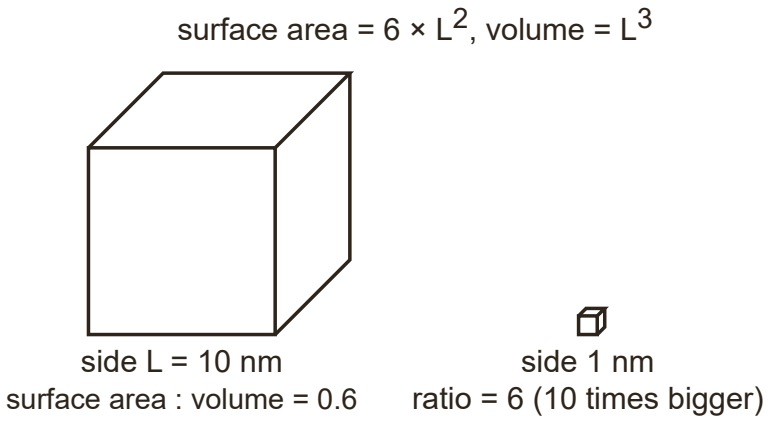
- **Nanoscience** is about structures that are **1 to 100 nm** in size, containing roughly a few hundred atoms.
- 1 nanometre (nm) = 1×10^{-9} m (one billionth of a metre).
- **Nanoparticles** are 1 to 100 nm across.
- **Fine particles ($PM_{2.5}$)** are 100 to 2500 nm across (1×10^{-7} m to 2.5×10^{-6} m).
- **Coarse particles (PM_{10})** are 2.5×10^{-6} m to 1×10^{-5} m across (2500 to 10 000 nm). Coarse particles are often called **dust**.
- An atom has a radius of about 0.1 nm (1×10^{-10} m), and a small molecule is usually less than 1 nm across. So a 10 nm nanoparticle is about 50 atoms across.



Nanoparticles are 1 to 100 nm: much bigger than atoms, much smaller than fine dust.

Surface area to volume ratio

- For a cube with side L: surface area = 6 × L^2 (six square faces), volume = L^3, and surface area ÷ volume = 6 ÷ L.



Make the side 10 times smaller and the surface area to volume ratio gets 10 times bigger.

- Side 10 nm: surface area 600 nm^2, volume 1000 nm^3, ratio 0.6 nm^{-1}. Side 1 nm: surface area 6 nm^2, volume 1 nm^3, ratio 6 nm^{-1}.
- For the **simplest whole number ratio**, divide both numbers by their highest common factor. E.g. side 5 nm: surface area 150 nm^2, volume 125 nm^3, so 150 : 125 = 6 : 5.
- So when the side of a cube **decreases by a factor of 10**, the surface area to volume ratio **increases by a factor of 10**.
- Nanoparticles are so small that a large fraction of their atoms are at the surface.

Why size changes properties

- Because of their very high surface area to volume ratio, nanoparticles may have **different properties** from the same material in bulk (in large pieces).
- For example, a metal that is unreactive in bulk can be a good catalyst as nanoparticles, because far more of its atoms are exposed at the surface.
- It can also mean that **smaller quantities** of a nanoparticle material are needed to be effective than of the same material with normal-sized particles.

How to answer each type of question

Convert sizes and classify particles

2 to 3 marks | Grade 5

1. Convert every size to the same unit, usually nm: multiply metres by 10^9.
2. Compare with the ranges: nano 1–100 nm, fine 100–2500 nm, coarse 2500–10 000 nm.
3. Take care with standard form: 10^{-7} m is bigger than 10^{-8} m.

Example. The table gives the diameters of three particles.

Particle	Diameter in m
P	4×10^{-8}
Q	6×10^{-6}
R	1.5×10^{-7}

Classify each particle as a nanoparticle, a fine particle or a coarse particle.

Model answer.

P = 40 nm, so a nanoparticle (1)
Q = 6000 nm, so a coarse particle (1)
R = 150 nm, so a fine particle (1)

Compare the size of a nanoparticle with an atom

2 marks | Grade 5

1. Check whether you are given a radius or a diameter; diameter = 2 × radius.
2. Put both sizes in the same unit.
3. Divide the larger size by the smaller one.

Example. An atom has a radius of about 0.1 nm. A nanoparticle has a diameter of 30 nm. Estimate how many atoms would fit in a line across the diameter of the nanoparticle.

Model answer.

Diameter of the atom = 2 × 0.1 = 0.2 nm (1)
30 ÷ 0.2 = 150 atoms (1)

Calculate the surface area to volume ratio of a cube 3 marks **Grade 5**

1. Surface area = 6 × side × side (a cube has six square faces).
2. Volume = side × side × side.
3. Ratio = surface area ÷ volume. Give it with units (nm^{-1}) or as a ratio to 1. For the simplest whole number ratio, divide both by their highest common factor.

Example. A nanoparticle is a cube with sides of 20 nm.
Calculate its surface area to volume ratio.

Model answer.

Surface area = 6 × 20 × 20 = 2400 nm^2 (1)

Volume = 20 × 20 × 20 = 8000 nm^3 (1)

Ratio = 2400 ÷ 8000 = 0.3 nm^{-1} (or 0.3 : 1) (1)

Explain how the ratio changes when the particle size changes 2 marks **Grade 5**

1. Find the factor by which the side has changed.
2. The ratio changes by the same factor, the other way: side 10 times smaller → ratio 10 times bigger.
3. Check with the formula ratio = 6 ÷ side.

Example. A second nanoparticle is a cube with sides of 2 nm.
How many times larger is its surface area to volume ratio than that of a cube with sides of 20 nm? Explain your answer.

Model answer. 10 times larger (1). The side is 10 times smaller, and the ratio = 6 ÷ side, so the ratio is 10 times bigger: 6 ÷ 2 = 3 nm^{-1} compared with 6 ÷ 20 = 0.3 nm^{-1} (1).

Don’t lose marks

- Using the radius of an atom when you need its diameter, or the other way round. Read which one the question gives.
- Getting standard form comparisons backwards: 1 × 10^{-9} m is smaller than 1 × 10^{-7} m.
- Forgetting the 6 in the surface area of a cube, or using only one face.
- Saying the ratio decreases as particles get smaller. Smaller particles have a larger surface area to volume ratio.
- Writing 'nanoparticles have a large surface area'. Say 'a high surface area to volume ratio'.
- Giving a decimal when the question asks for the simplest whole number ratio: 2400 : 8000 simplifies to 3 : 10, not 0.3.

More tips

Memory tricks

- Size ladder in nm: atom about 0.1 (radius) → nanoparticle 1–100 → fine 100–2500 → coarse 2500–10 000.
- $PM_{2.5}$ and PM_{10} give the upper size in micrometres: 2.5 µm = 2500 nm and 10 µm = 10 000 nm.
- Cube shortcut: surface area ÷ volume = 6 ÷ side. Use it to check your full working.
- Metres to nm: add 9 to the power of ten, e.g. 4×10^{-8} m = 4×10^{1} nm = 40 nm.

Exam technique

- Show each step of a surface area to volume calculation: surface area, then volume, then the ratio. Each step can earn a mark.
- Put all sizes in the same unit before you compare them.
- When explaining why nanoparticles behave differently, always use the phrase 'surface area to volume ratio'.

What each grade needs

What you need to be able to do, from the first marks up to the top grade.

Grade 4 — **State the size range of nanoparticles**
Nanoparticles are 1 to 100 nm across and contain a few hundred atoms.

Grade 5 — **Convert between nanometres and metres**
1 nm = 1×10^{-9} m, so 50 nm = 5×10^{-8} m.

Grade 5 — **Classify particles as nano, fine or coarse**
Nano 1–100 nm; fine ($PM_{2.5}$) 100–2500 nm; coarse (PM_{10}) 2500–10 000 nm.

Grade 5 — **Compare nanoparticle sizes with atoms and molecules**
An atom has a radius of about 0.1 nm, so a nanoparticle is tens to hundreds of atoms across.

Grade 5 — **Calculate a cube's surface area to volume ratio**
Surface area = 6 × side^2; volume = side^3; ratio = surface area ÷ volume.

Grade 5 — **Explain how the ratio changes with size**
If the side of a cube is 10 times smaller, its surface area to volume ratio is 10 times bigger.

Grade 5 — **Explain why nanoparticles behave differently from bulk material**
Their very high surface area to volume ratio can change their properties, and smaller quantities can be effective.

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