Bio Factsheet

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# Surface Area and Volume

The surface area to volume ratio is a crucial biological concept. It helps explain, amongst other things why:

- organisms that rely upon diffusion are condemned forever to be small
- tapeworms are extremely efficient parasites
- as organisms get bigger, they need internal transport systems
- microvilli are an essential part of our intestines
- plants that live in arid areas have unusual –shaped leaves
- Hippos need to stay in the water during the day

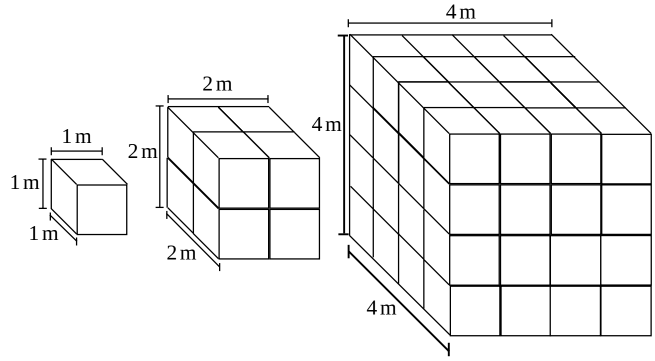
This concept appears on the exam papers of all the Boards every year – but it often comes up in very well camouflaged questions!

This Factsheet will help you to:

- understand the importance of the concept, and
- spot it in exam questions

The surface area of an organism is the area its outer surface covers. Imagine a square organism (Fig 1).

**Fig 1. Surface area to volume ratios of differently sized cubes**




| | | | |
|---|---|---|---|
| **surface area** | $6m^2$ | $24m^2$ | $96m^2$ |
| **volume** | $1m^3$ | $8m^3$ | $64m^3$ |
| **surface area:volume** | 6:1 | 3:1 | 1.5:1 |

Its surface area is 6 x $L^2$ where L =the length of one side. If L =1cm then its SA =$6cm^2$
Its volume is $L^3$ or $1^3 = 1m^3$
Its SA to V ratio is 6:1 = 6

Now, let's double its size:
SA = $6x2^2 = 24cm^2$ i.e. area has DOUBLED
V = $2^3 = 8cm^3$ i.e. volume has OCTUPLED
Its SA:V ratio is 24:8 = 3:1

Now lets double the size again:
SA = $6x4^2 = 96\ cm^2$
V = $4^3 = 64\ cm^3$
SA:V ratio is 96:64 = 1.5:1

So, as organisms get bigger, their surface area increases by the square of their size, but their volume increase by the cube of their side length. **The increase in volume is always greater than the increase in surface area**. This is true for cubes, spheres, or any other object whose size is increased without changing its shape.

**So: The smaller the organism, the greater it's SA :V ratio**
**As an organism gets bigger, its SA:V ratio goes down**

Organisms have both physiological and anatomical adaptations to compensate for changes in the surface area to volume ratio associated with size differences.

## Heat loss

Small animals have a large SA:V ratio
∴ If they are homethermic (i.e. a bird or a mammal) they will lose heat much faster than a large animal
∴ they must therefore produce more heat to keep warm
∴ they tend to have higher metabolic rates than large homeotherms

Sometimes, you will be expected to apply this knowledge to try to explain the behaviour of large mammals that live in hot climates. For example, the hippopotamus is a large mammal that lives in tropical Africa.

**Question**: Using your knowledge of SA:V ratios, suggest why the hippo spends most of the day partly submerged in lakes and rivers, coming out at night to feed on vegetation.

A large mammal will have a ***small*** SA:V ratio ( look at Fig 2 which illustrates how much volume there is for each square centimeter of skin).

**Fig 2 hippo**

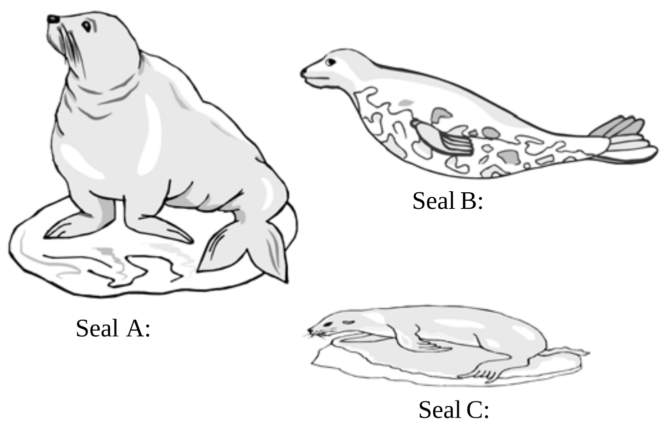
**Answer**: The huge mass of cells will be producing metabolic heat from respiration;
There is relatively little skin surface to lose this heat/small SA:V ratio
In any case, it's in the tropics - air temperatures are high;
Its fat stores will limit heat loss;
Hence, it spends the hot days in the cooler water;
Emerging during the much cooler nights.

**Note: Hippos are not on any A level spec – the examiners expect you to be able to apply simple biological principles to new situations**

All marine mammals are relatively large sized in comparison with terrestrial mammals. Even the smallest seal, the ringed seal, weighs 50 kilograms. Once again, the relative size of different seals may be an indication of the temperature of the environment in which they live.

Fig 3 shows three species of seal (a mammal), A, B and C.

**Fig 3.**




Seal A:
Habitat: very cold seas of the Arctic
length 2.3, mass 380 kg.

Seal B
Habitat: slightly warmer seas
length 1.4 m, mass 180 kg

Seal C
Habitat: warmest of the three habitats
length 0.6 m mass 80 kg

**Question**: How is seal A adapted for life in the very cold arctic waters?

**Answer:** Small SA:V ratio;
Therefore rate of heat loss low;
Thick blubber offers insulation;
Small limbs so reduced area for heat loss;

**Note: it would not be correct to say that seal A loses least heat; it has a bigger surface area so it will lose a lot, but the rate of heat loss will be less. In the exam, be precise.**

## Internal transport systems

Small, unicellular organisms have a large surface area over which gas exchange may take place. Diffusion is adequate for supplying oxygen and getting rid of carbon dioxide across the outer cell surface membrane. But as an organism gets larger, its surface area to volume ratio decreases and this makes a specialised transport system essential (Fig 4).

**Fig 4. Specialised transport system**

Amoeba

- Diffusion is fast enough over very small distances

cheetah

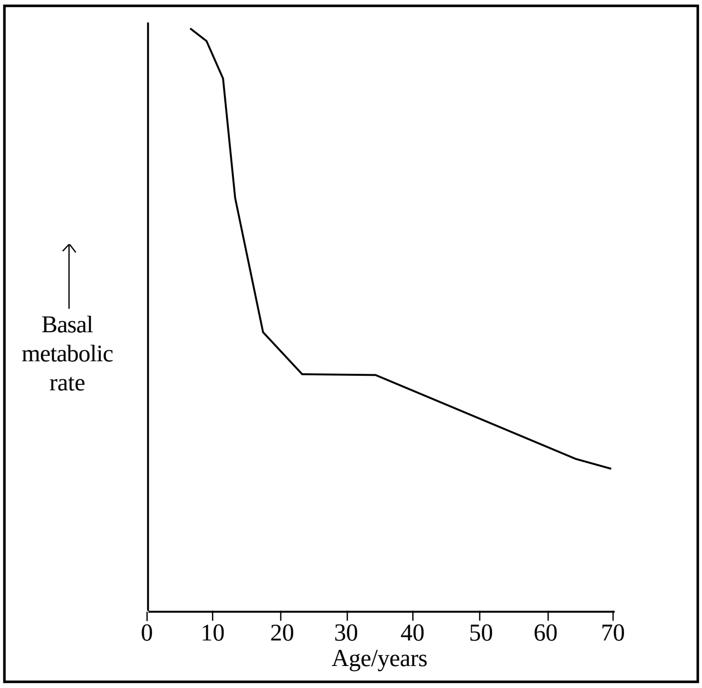
- Diffusion path is too long/diffusion is too slow in large, multicellular organisms which are active
- Have low SA:V ratios
  Multicellular organism needs more oxygen, faster
- Allows aerobic respiration to generate sufficient ATP
- Needs to get rid of $CO_2$ or urea quickly because they are toxic

One response to the problems of declining SA:V ratios with increasing size is to increase surface area –many organisms exhibit such structures:
- leaves on trees
- microvilli on the lining of the small intestine
- root hairs
- extensive capillaries
- the convoluted walls of arteries
- flattened segments of tapeworm to aid absorption and reduce resistance to the flow of substances through the intestine
- alveoli in lungs
- lamellae in gills

**Basal metabolic rate (BMR)**

The basal metabolic rate is the amount of energy required to maintain basic physiological functions when at rest. Fig 5 shows the changes in BMR in males between the ages of 10 and 70.

**Fig 5. Basal metabolic rate**




It may come as a surprise to see how the BMR declines sharply between the ages of 10-20. BMR is, in fact, directly proportional to body surface area. Between the ages of 10-20 years the BMR declines rapidly as adolescent growth leads to a decrease in S.A. / mass.

## Red blood cells

**Question:** How does the shape of a red blood cell allows it to take up a large volume of oxygen in a short time?

**Anawer**. It has a large surface area to volume ratio;
For diffusion;

> ***Exam Hint***
> *Here is an extract from a Chief examiner's report on a similar question:*
>
> *Candidates often chose to ignore the instruction about **shape**, and produced inappropriate answers relating to there being no nucleus or the red blood cell having haemoglobin. No credit was given for responses that talked only about the surface area of the cell; the examiners wanted the all-important principle of the surface-area to volume ratio.*

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## Conclusion

The concept of surface area: volume ratios comes up in lots of different topics and it isn't always immediately obvious that the question is asking about this concept. Make sure that you understand the principle and practice using the key terms

**Practice Questions**

1. (a) The table below shows the size of 4 animals. Complete the table by calculating the surface area, volume and SA :V ratio for each animal.

| Animal | Size (cm) | **Surface Area ($cm^2$)** | **Volume ($cm^3$)** | **Surface area to Volume Ratio** |
|---|---|---|---|---|
| 1 | 1x1x1 | | | |
| 2 | 2x2x2 | | | |
| 3 | 3x3x3 | | | |
| 4 | 4x4x4 | | | |

(b) All other things being equal, which organism would have most difficulty keeping warm in a cold environment? Explain your answer.

2. The equation below represents Fick's Law of diffusion across membranes

$$J = DA\frac{\Delta c}{\Delta x}$$

J = net rate of diffusion
D = diffusion constant of dissolved solute
A = area of the membrane
Δc = concentration difference across membrane
Δx = thickness of membrane

(a) Use Fick's Law to explain why the efficiency of oxygen transport across the alveolar surfaces of a mammalian lung is improved by the surfaces:
(i) having a large area.
(ii) being a thin membrane.
(iii) having an efficient blood supply.

## Answers

1. (a)

| | | | |
|---|---|---|---|
| Animal 1 | 6cm² | 1m² | 6:1 |
| Animal 2 | 24cm² | 8m² | 3:1 |
| Animal 3 | 54cm² | 27m² | 2:1 |
| Animal 4 | 96cm² | 64m² | 1.5:1 |

2. (a) (i) if A is large then J must be large and so more oxygen can be diffused;
(ii) if Δx is small then J must be large and so more oxygen can be diffused;
(iii) an efficient blood supply will carry oxygen away more efficiently;
thus Δc will be large and so J will be large so more oxygen can be diffused;

(b) as Amoeba grows the distance for oxygen to diffuse from the (surrounding) water into the centre of the cell increases;
this is Δx and if this is increased J is reduced;
thus the central regions of the Amoeba cell become deprived of oxygen above a certain cell size;
division reduces it to a more suitable size for efficient gas exchange;