Welcome to the World of Fungi

In the beginning

'Can you believe that fungi have been around on earth longer than humans?'

- ► Earth is approximately 4.6 billion years old.
- ► Humans have been on earth for about 200,000 years.
- ► Fungi have been on earth for about 500 million years.

Fungi are so tough and well adapted to their environment that they outlived the dinosaurs. The scientists that study fungi (mycologists) have so far identified more than 100,000 species, but estimate that there could be 1.5 million species all over the world.

►Question: Why do you think not all species have been found?

There are so many living organisms on earth that scientists have classified them into 5 kingdoms:

1. Animals
2. Plants
3. Bacteria
4. Protists
5. **Fungi**

[Note: all those names are plural. If you have one mushroom, it is a fungus; if you have two they are fungi.]

Let's focus on fungi

What do you think of when you read the word.....**fungi?**

.....mushrooms and toadstools?

These answers are correct, but they aren't the only answers.

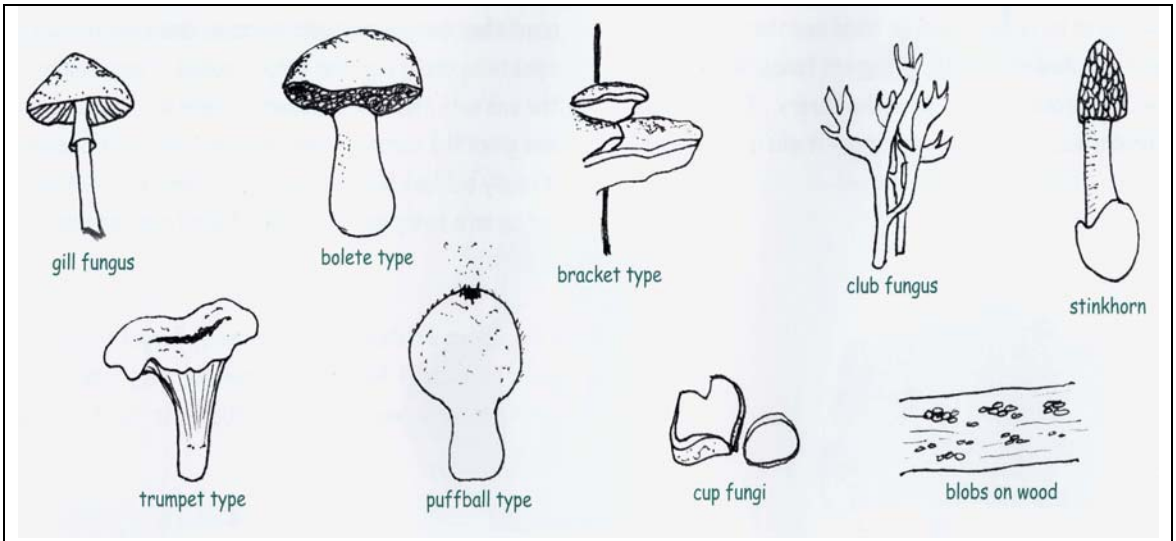
Bacteria are called **prokaryotes** whilst fungi are **eukaryotes** and may be single celled (yeast) or filamentous and multicellular (with 100s or 1000s of cells.)

Filamentous multicellular fungi include:

mushrooms and toadstools
moulds
cup fungi
bracket fungi
…and lots of others

They all have different:

sizes
shapes
colours
smells
textures



From *Fungus Fred Goes Foraying* by Margaret Hadley

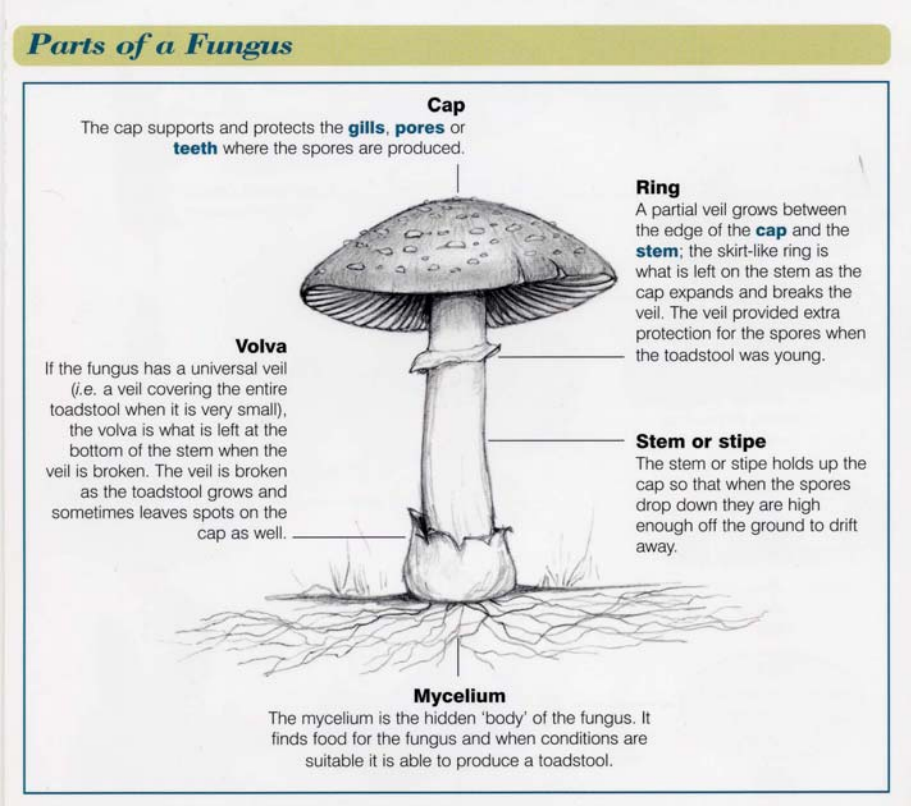
What are Fungi Made of?

If you pull a shop-bought mushroom apart with your fingers you'll see that the body of the mushroom is made up of a network of threads or fibres – these are called **hyphae.** A **hypha** is characteristic of fungi. It is a long, growing tube.

Draw and label diagrams of an animal cell and a hypha in this box.

Animal Cell **Hypha**

The large network of hyphae is called the **mycelium**. It is responsible for finding food sources for the fungus.



From *The Fungi Name Trail* by Liz Holden & Kath Hamper

Growth of a mushroom occurs in different stages. The mycelium grows under the soil, searching for food.

This searching and branching outwards develops the mycelial network. Only when conditions are correct, does the mycelia grow upwards out of the soil to produce a **mycelial knot** that eventually grows into the visible mushroom.

►**Experiment: How the Mushroom got its Spots.** Try the experiment in the booklet for yourself to learn a bit more about mushroom growth.

Fungi can be:
1. Single celled
OR
2. Septate
OR
3. Aseptate

Use this box to draw and label diagrams of a single celled fungus (yeast), a septate fungal hypha, and an aseptate fungal hypha.

Why aren't Fungi Plants?

Draw and label diagrams of a plant cell and a hypha in this box. Label them to remind yourself how they compare with one another.

Plant Cell	Fungal hypha
Cellulose cell wall Chloroplasts	Cell wall made of **chitin** No chloroplasts

KEY DIFFERENCE: Feeding.

- Plants make their own food, converting light energy gained from the sun into chemical energy, using their chloroplasts. This is called photosynthesis.
- Animals engulf their food (even individual animal cells do this).
- Fungi secrete enzymes into their food to digest it externally; they then absorb the small molecules produced by the digestion as their nutrients.

Fungi differ in the way they feed. They can be:

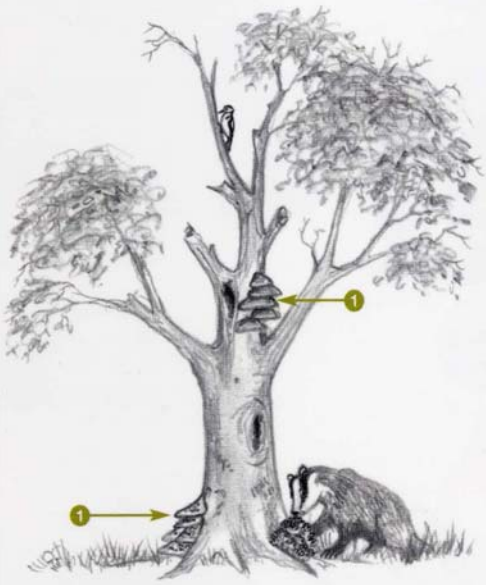
1. **Saprotrophic** (obtaining their nutrients by decomposing [and therefore recycling] dead organic materials)
2. **Symbiotic** (in a close, mutually-beneficial relationship with another organism)
3. **Parasitic** (living on or in another organism (the 'host') and taking their nutrients from the host; this may injure and may kill the host).

How do fungi feed?

Unlike plants, fungi cannot gain their energy directly from the sun by photosynthesis; they have had to develop other ways to get it.

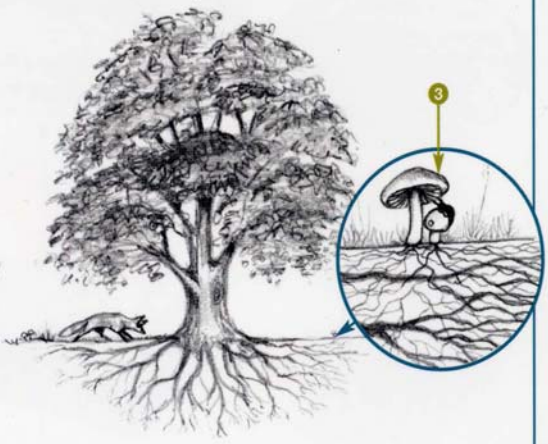
The majority of the fungi are, however, either saprotrophic (**decomposer**) fungi or **symbiotic** fungi.

Decomposer fungi are busy helping to break down dead wood 2 and other plant and animal material. The fungi absorb some of the nutrients but most goes back into the woodland ecosystem so that it can be recycled.



A few of the fungi do this by feeding off living trees or plants 1, sometimes killing them. These fungi are **parasites** but it is important to remember that they have a vital role in the natural woodland, as they remove old or weak trees and create a dead wood habitat that insects and other animals can use.

If you look carefully at the pictures you will find lots of animals. Try and work out some of the food chains here, starting with the energy flow from the sun and ending with a top predator – make sure you include a fungus along the way!



Symbiotic fungi actually establish a physical link with another organism (plant, tree or alga) 3 so that both can benefit by the arrangement. For example, the mycelia of some fungi grow around and sometimes into the roots of trees to enable the exchanges to take place. Over 80% of higher plants and trees gain additional mineral salts in this way, particularly useful where the soil is poor. In return the tree or plant sends some of its own surplus energy (carbohydrates) down into the fungus!

From *The Fungi Name Trail* by Liz Holden & Kath Hamper

Hyphal growth is characteristic of fungi

Hyphae grow at their **tips**; they search for areas in the soil which contain plenty of food. They don't engulf their food like animals, so **how does the food enter the hyphae?**

The answer is **enzymes digest the food outside the hyphae**. Special enzymes are released (secreted) from the hyphal tips and can break down large complex food into smaller soluble food that the hyphae can then absorb.

Where are Fungi Found?

Fields Forest floor On trees Back garden	Obvious?
On ships Window frames Cheese and bread (food) Between your toes In your mouth On your skin	Not so obvious?

►Question: How many uses for fungi can you think of?

SAFETY

Some fungi are edible, but some are POISONOUS

If you find a fungus growing wild

DON'T EAT IT

DON'T TOUCH IT

Find the correct explanation to complete the statement.

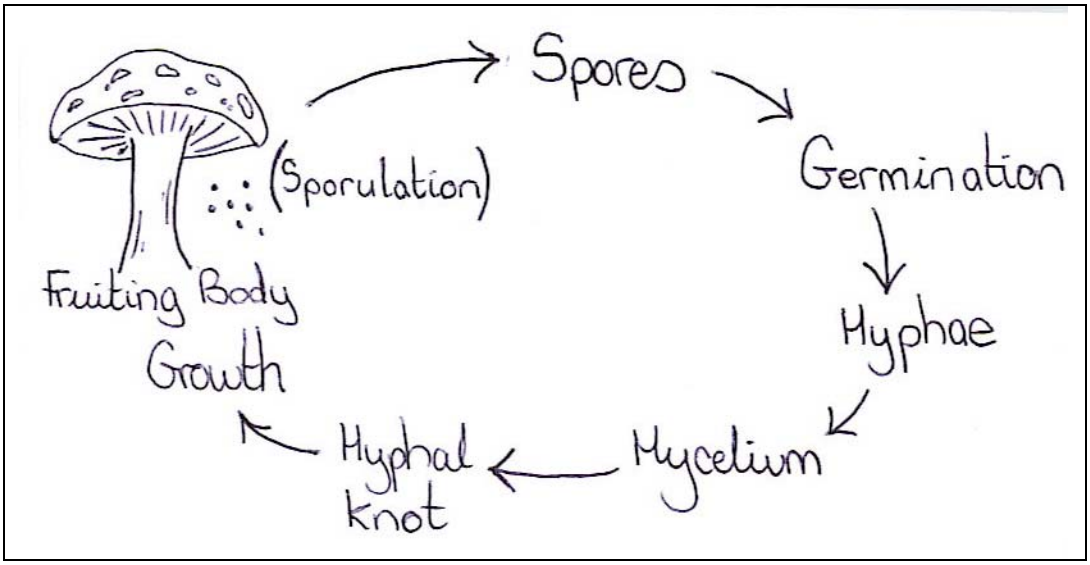
Draw a line linking the start of the sentence in the left-hand column with the end of the sentence in the right-hand column.

1. Fungi are…	**…special enzymes that break down complex food into smaller soluble food.**
2. Fungal parasites...	**…500 million years ago.**
3. Fungal decomposers...	**…feed off living trees and plants and can sometimes kill them.**
4. Fungal symbionts…	**…break down dead wood, plant and animal material.**
5. Fungi can be found...	**…eukaryotes.**
6. Fungi feed via...	**…make physical links with another organism. Both benefit from the relationship.**
7. Fungi first appeared on earth...	**…(a) in woodland areas, (b) between our toes, (c) on ships.**

Reproduction and Conservation

Rewind . . . . . .

During last lesson we discussed how and where fungi grow. Let's go one step further on and focus on how fungi reproduce.



As this simplified diagram shows, the fruiting body produces spores (process called sporulation); these then germinate after they arrive in their ideal environment (which might be soil, or a leaf surface, or some rotting leaves, etc.) and begin to produce hyphae and then the mycelial network. Further growth produces the **hyphal knot** and eventually the fruiting body. Spores are released and the whole process starts all over again.

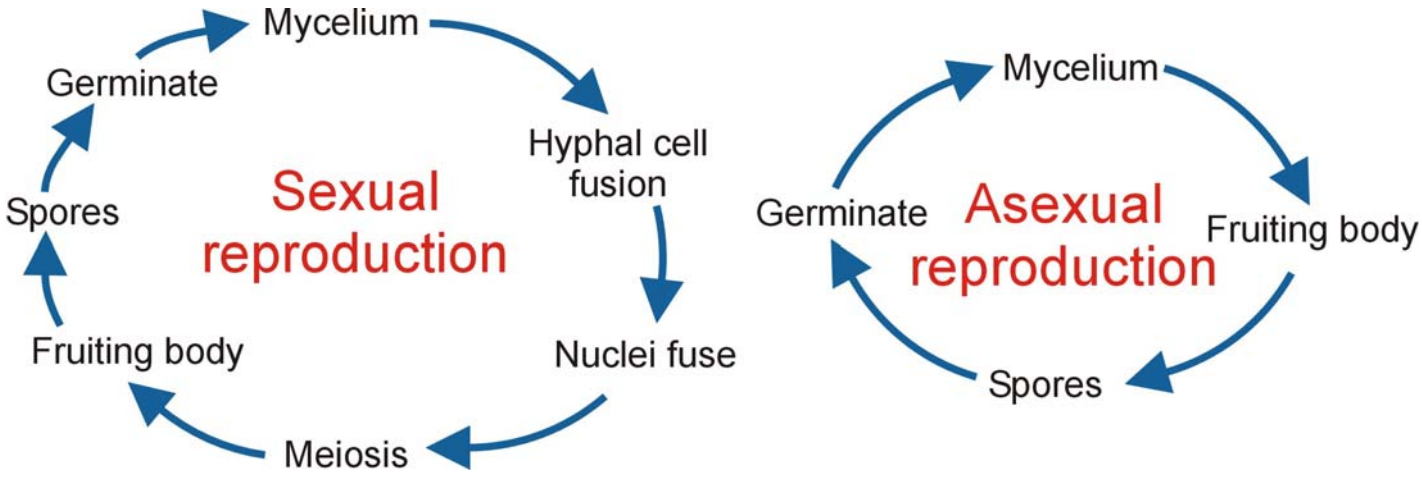
Do you remember that plant reproduction can be sexual or asexual? Well, it's just the same for fungi too.

- ► Most fungi reproduce **both** sexually and asexually
- ► Some reproduce **only** sexually
- ► And the rest reproduce **only** asexually

Recap . . . . . .

Sexual Reproduction:	Involves the **mixing** and **recombination** of genetic material from two parents of opposite sexes. Produces **genetically different** offspring. Process includes: cell fusion, nuclear fusion, recombination, **meiosis and mitosis.**
Asexual Reproduction:	Involves copies of only a single parent being made. Produces **genetically identical** offspring. Process includes: **NO** cell fusion, **NO** nuclear fusion, **and ONLY mitosis.**

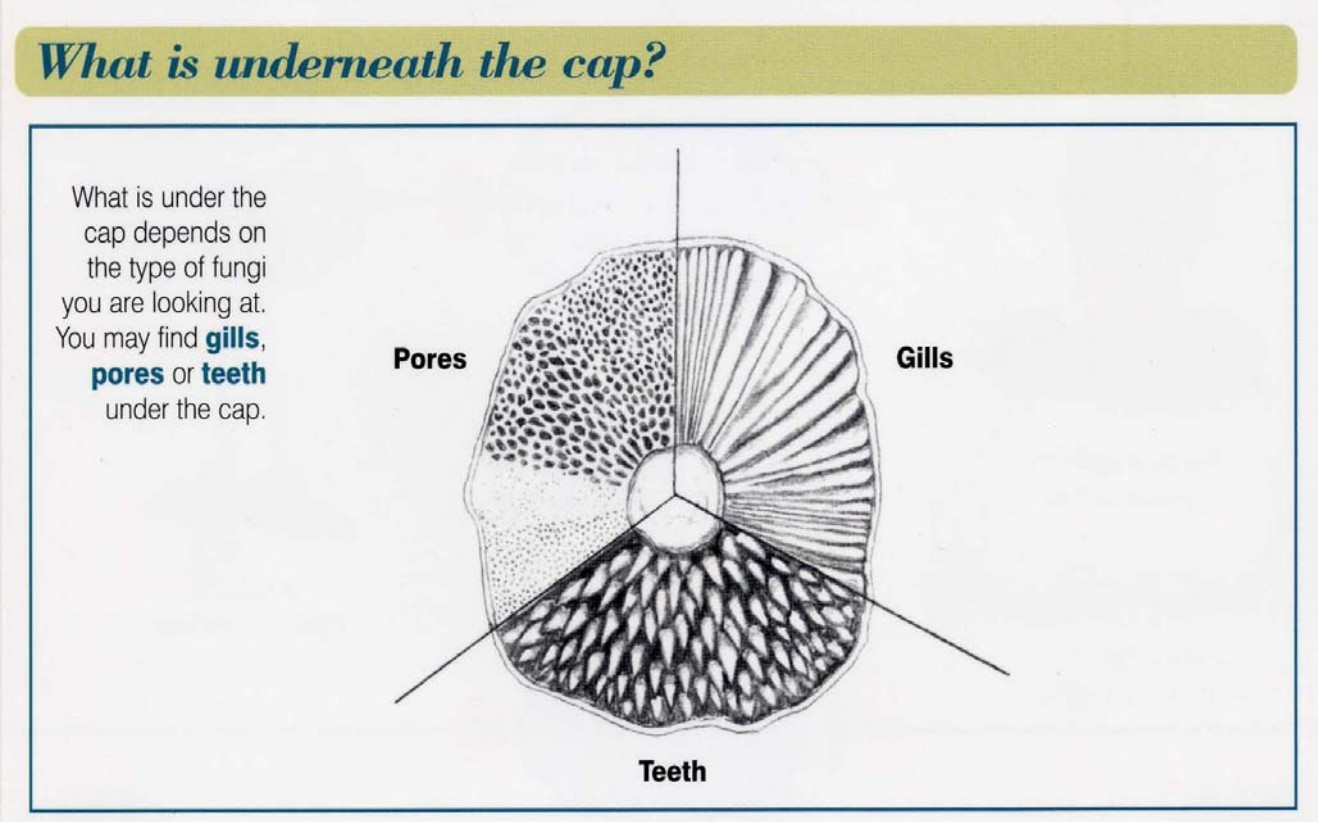
Cell cycles in Summary:



Where are Spores Produced?

Answer: from the **hymenium** ►	The tissue layer of the fruiting body that contains spore-making cells.

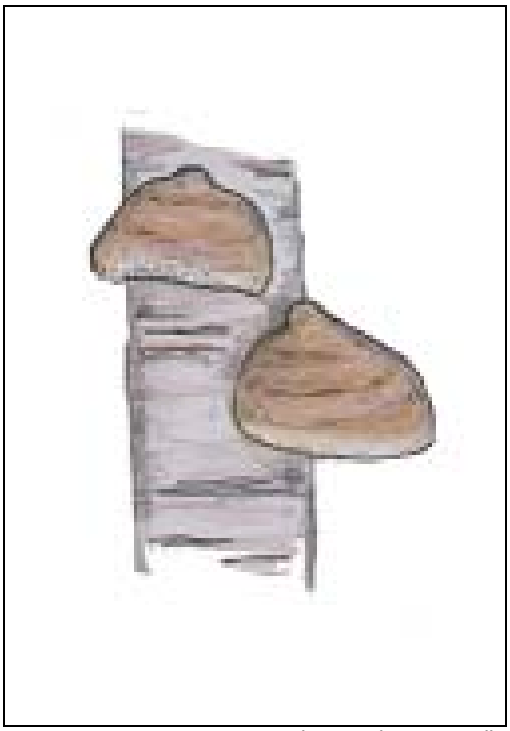
Let's look at the mushroom as an example.....



From *The Fungi Name Trail* by Liz Holden & Kath Hamper

These three structures (named in the picture above) are all covered with the hymenium tissue layer that **contains** and **releases** spores.

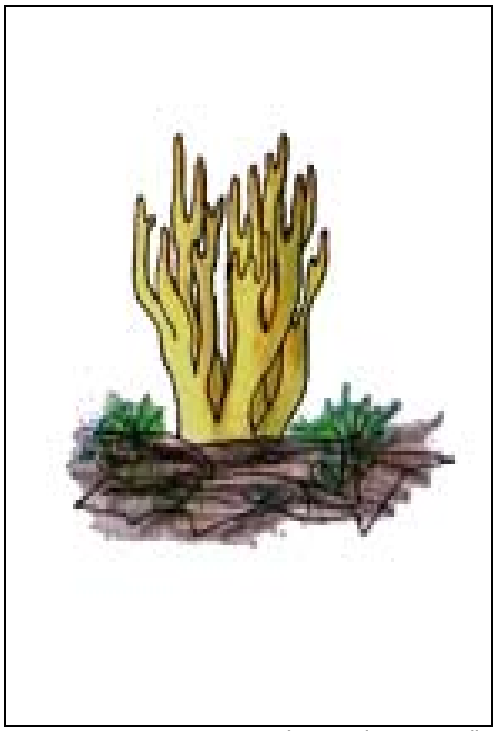
What about other fungal structures?



From *The Fungi Name Trail*

Birch Polypore
Piptoporus betulinus

This bracket fungus releases spores from pores **underneath its cap**



From *The Fungi Name Trail*

Yellow Stagshorn
Calocera viscosa

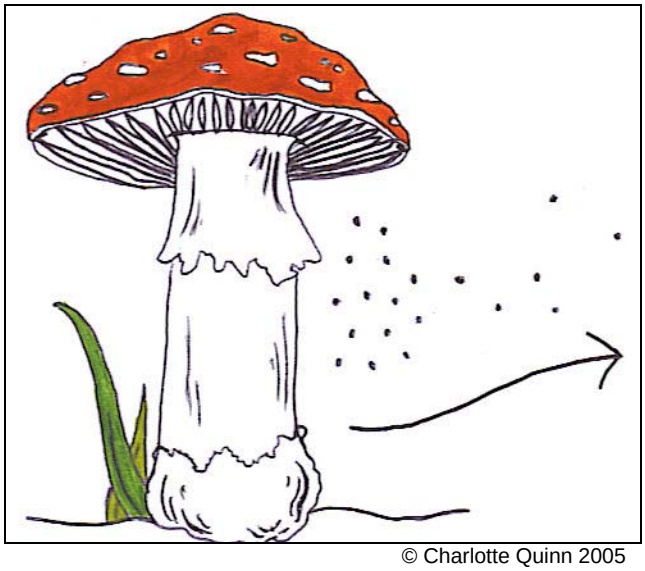
While this coral fungus can release spores from pores **all over its body**

How are Spores Dispersed?

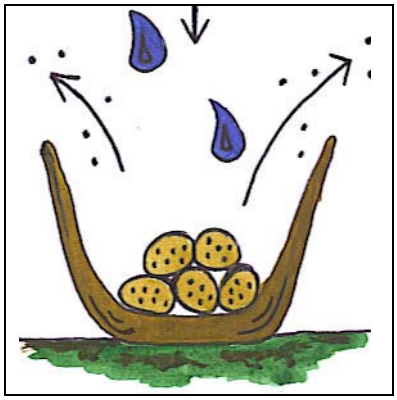
To ensure survival of the species, a fungus must produce and release spores as quickly as possible. These spores must be dispersed over large areas to avoid competition. There are many ways in which dispersal can occur:

- ► Wind
- ► Rain
- ► Insects
- ► Mechanical Processes

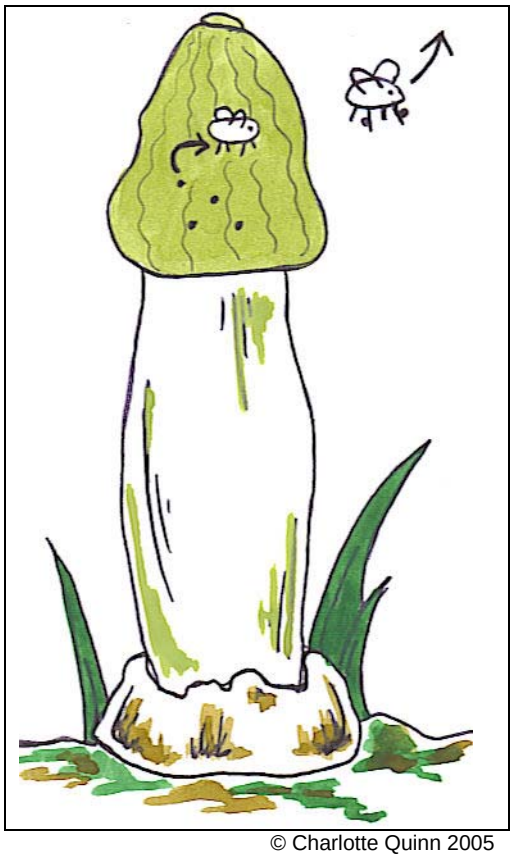
Wind ► *Amanita muscaria* is an example of the type of mushroom that releases spores from gills (vertical plates of tissue underneath the cap). The spores fall from the gills under the cap and are then carried away by air currents. They can be spread over large distances by the wind.



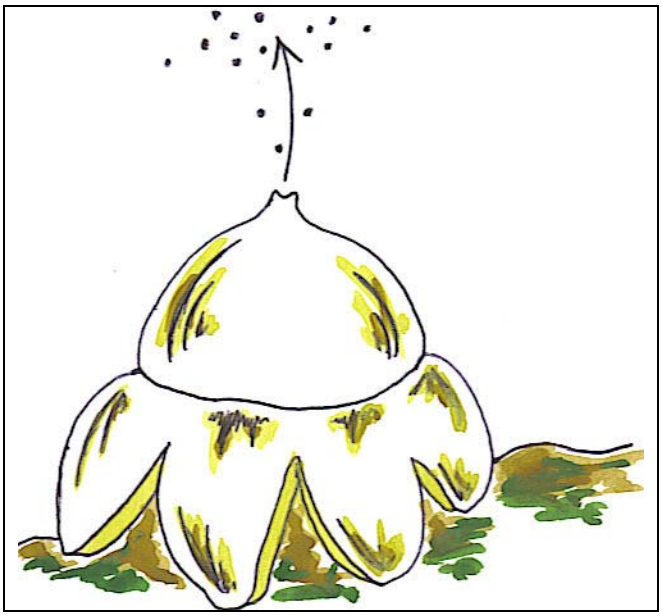
Rain ► The cup fungus *Crucibulum vulgare* or Bird's Nest Fungus has its spores dispersed by rain fall. Raindrops fall into the fungus fruit body and the rain splash forces the spores out and away from the fruit body.



Insects ► The spores of the Stinkhorn fungus, *Phallus impudicus*, are formed in a slimy secretion on the bell-shaped tip of the fruiting body. The fungus generates a foul smell – like rotting meat. Flies are attracted to the strong smell and the spores are transferred onto their legs and body and deposited where the fly next lands.



Mechanical Processes ► When the ball shaped fruit body of a puffball or earth star (like *Geastrum*) is disturbed (by an animal or by twigs, leaves or rain drops falling on it) the impact increases the air pressure inside and millions of spores are forced out on a jet of air that emerges through the pore on top.



Conservation and Management

All fungal species are extremely important for the maintenance of our planet. We have already discussed the role of fungi as decomposers - removing dead organic matter by breaking it down using enzymes.

►Question for class discussion : What would happen if fungi didn't exist?

You know quite a bit about what fungi do in nature, so think about it and imagine: what would happen if all fungi were killed off tomorrow?

Food webs show the many different types of plants, fungi and animals of a particular **ecosystem**. From them, we can understand the feeding patterns and energy flow within this system.

Use this box to draw an example of a food web (including fungi):

The Decline of Kingdom Fungi?

Reports from all over Europe suggest that in recent years there have been serious declines in the numbers of mushrooms and other fungi found in the forests. The question is: **WHY?**

There are several reasons; including:

► Increased large-scale picking of wild mushrooms for commercial sale	
► **Pollution** is a major factor because of:	• Air pollution • Acid rain • Water contamination from fertilizer 'run-off' • Desertification (e.g. around the Mediterranean Sea)
► Clearing of woodland areas	
► Lack of understanding of the roles of fungi in nature	

Save your fungi!

The problems have been identified, so let's focus on the **solutions**:

► Obey the law:	• The Theft Act (1968) • The Wildlife and Countryside Act 1981) both protect wildlife to some extent, and other legislation may apply to prevent picking
► Respect and caution:	Respect the natural habitat – avoid unnecessary damage and disturbance
► Conservation areas:	Some countries have vast areas protected by conservation controls
► Management:	Government guidelines for fertilizer usage in agriculture. On a larger scale, the Kyoto Agreement – carbon emission control

To save your fungi you might have to save the forest!

British Mycological Society promoting fungal science

My Favourite or Nastiest Fungus

Rewind . . . . . .

So far we have discussed the basics of fungi; what they are, their many sizes and shapes, growth, reproduction and conservation issues. Now it's over to you!

►Task:	**To work in a group of 2 to 5 people and produce a poster which illustrates your favourite or nastiest fungus.**

► The best poster wins a prize ◄

Where do we start?

- The first part of your task involves looking for information on the Internet. Six fungal names are provided on the next page along with website addresses you can access from your school computer room.
- The second part involves making the poster. You can present it any way you like (remember the best one gets a prize.)

►Get creative◄

Your poster **MUST** provide the following information:

► Common and scientific name of your chosen fungus
► A drawing with the structures labelled
► Where and when it is found
► How it feeds - is it a decomposer, saprotroph or parasite?
► Why it is your group's favourite or nastiest fungus

Fungal names

We suggest you look for the following (but that doesn't stop you looking for others…)

1. *Amanita muscaria*
The Fly Agaric

2. *Marasmius oreades*
Fairy Ring Champignon or Fairy Ring Fungus

3. *Phallus impudicus*
Stinkhorn fungus

4. *Piptoporus betulinus*
Bracket Fungus

5. *Amanita pantherina*
The Panther

6. *Aleuria aurantia*
Orange Peel

Websites

www.MushroomExpert.com
Click on 'Site Index.'

www.agarics.org
Click on 'Database.'

www.herbarium.usu.edu
Click on 'Fun Facts about Fungi.'

www.mykoweb.com
Click on 'California Fungi' and then click on 'Species Index.'

www.first-nature.com/fungi
Click on 'Identity Parade'

For *Aleuria aurantia* select Ascomycetes.
For *Phallus impudicus* select Gasteromycetes.
For *Amanita muscaria* select Amanitaceae.
For *Amanita pantherina* select Amanitaceae.
For *Piptoporus betulinus* select Poriales.

Table showing our fungus names and where information about them can be found.

Name	Mykoweb	Mush.Expert	Agarics	First-Nature
A. muscaria	+	+	+	+
M. oreades	+	+	+	
Ph. impudicus		+	+	+
P. betulinus		+		+
A. pantherina	+		+	+
Al. aurantia	+	+		+

Fungi and Industry

We have already discussed one major importance of Kingdom Fungi: they are decomposers and help remove dead organic matter from our ecosystems. We will now go one step further and discuss how fungi and fungal products help us **directly**.

What is Biotechnology?

Biotechnology: industries use microbes, like bacteria and fungi that produce extremely useful substances. Some of these products are beneficial to our health and wellbeing.

►Question:	**Can you think of any products that depend on the use of fungi at any stage during manufacture?**

Use the box below to make a table listing those you can think of:

Fermentation and Yeast

► Yeast is a single-celled fungus	
► Yeast can respire:	► with oxygen (called aerobic respiration) ► without oxygen (called anaerobic respiration)
► During anaerobic conditions, yeast ferments sugar to produce alcohol, carbon dioxide and water in the process of **fermentation.**	
► Equation: Yeast + Glucose → Alcohol + Carbon dioxide + Water [NOTE: that the same chemistry is used in brewing and baking fermentations, but brewing uses the alcohol, and baking uses the carbon dioxide.]	

Brewing Industry ►	Brewer's yeast (*Saccharomyces cerevisiae*) ferments sugars in cereal grains to produce **alcohol**, in addition to various other products, producing beers and lagers.
Baking Industry ►	Baker's yeast (*Saccharomyces cerevisiae*) ferments sugars in the flour, but this time **carbon dioxide** is the useful product of fermentation. When the yeast in bread dough releases carbon dioxide it makes bubbles in the dough and causes the dough to 'rise' (increase in volume). The alcohol produced evaporates during baking.
Myco-protein ►	The product called Quorn is myco-protein. It is NOT a yeast or a mushroom, but a filamentous fungus called *Fusarium venenatum*. Myco-protein is used as an alternative to meat in health- and vegetarian products.

Find out more about the benefits of Myco-protein (Quorn) and discuss them. Find the information that will enable you to complete the table below with the amounts of each ingredient:

	Protein	Dietary Fibre	Fat
Myco-protein			
Beef steak			

Supermarket Challenge

Earlier we asked you to list some products that depend on the use of fungi in their manufacture. The table below includes a few you may not have thought of. Find out **HOW** they depend on fungi and write some notes in the last column of the table.

Marmite ►		
Fizzy Drinks ►		
Soy Sauce ►		
Chocolate and Coffee ►		

Local Industry

There are probably companies close to you and your school that use fungi or fungal products in their manufacturing processes. You could use local business directories to find out about them and then look at their websites to get more information.

Here's an unusual example:

The British Textile Technology Group (BTTG) is based in Didsbury in Manchester and works with the Welsh School of Pharmacy in Cardiff. Together they have designed and produced a range of filamentous fungal materials that help with the healing of wounds.

When you cut your finger you'll probably use a plaster to cover it up until it's healed. Even if you had a deep cut and had to go to hospital, the nurses would place a sterile pad over the wound and bandage it up. What these companies have produced incorporates filamentous fungi (the mycelial network) to produce a plaster with a difference:

► The secret's in the chitin (which maintains the rigidity and structure of fungal cell walls).

► Many experiments have been conducted which suggest that chitin can speed up the healing of wounds.

► It is thought that chitin actually encourages the growth of fibroblasts into the wound. Fibroblasts help build new tissue.

► The process has the potential to treat chronic ulcers and bed sores in hospital patients.

► If a patient's wounds heal faster then hospital and nursing resources will be saved.

► Discuss: Can you think of any other uses for this product?

How Can Fungi Benefit Our Health?

None of the products we have discussed so far are really essential for survival. Believe it or not, we can survive without chocolate and our favourite fizzy drinks! These products are manufactured for our enjoyment and to improve the quality of life.

However, for some people fungal products are really needed to treat infections, prevent serious diseases, or to improve poor diet. Some of these essential products are in the form of:

► **Antibiotics**

► **Statins**

► **Immunosuppressives**

► **Vitamins**

Use the information in the tables below as class discussion points.

Antibiotics ►	Antibiotics are used to treat bacterial and fungal infections. You probably know about **penicillin** -produced by the mould *Penicillium notatum* and discovered by Alexander Fleming in 1928. Other examples of antibiotics derived from fungi are: Cephalosporin from *Cephalosporium* sp. and Griseofulvin from *Penicillium griseofulvum* and *Penicillium patulum*. Today, most antibiotics used in medicine are derived from bacteria. Antibiotics produced by bacteria include streptomycin and terramycin.
► Discuss the effect of 'wonder drugs' on society (imagine the effect if antibiotics were not available). Discuss the effect of resistance to the drug in the disease-causing organism (e.g. newspaper stories about MRSA). How might you combat that? What's involved in finding new antibiotics?	

Statins ►	Statins are products of metabolic reactions in fungi. Lovastatin comes from *Aspergillus terreus* strains; mevastatin from *Penicillium citrinum*. Statins inhibit an enzyme involved in the synthesis of cholesterol and they've become very important for control of cholesterol levels in patients. **Cholesterol** is made in the liver, but we also get it from our food. Diets high in fat result in a build up of cholesterol in the arteries and this can lead to heart attacks or strokes.

► Discuss the influence of food on health and the use of medicines to control metabolism. Can you think of other examples?

Immuno-suppressives ►	Immune suppressants are essential for organ transplant patients. The T cells of the **human immune system** recognise the new organ as 'foreign' and begin to destroy the organ. The filamentous fungus called *Tolypocladium inflatum* was found to produce Cyclosporin A. This drug prevents organ rejection by inhibiting T cell activation.

► Discuss the ethics of organ donation and transplantation. What's involved in giving permission for a deceased loved-one's organs to be used for transplantation? Discuss the impact (on people and their families) of life-long, life-preserving medication.

Vitamins ►	All fungi are a good source of vitamins. Brewer's yeast synthesises B group vitamins; so yeast extract and yeast tablets are popular vitamin supplements. In industry the fungi *Nematospora gossypii* and *Eremothecium ashbyi* are now used to produce B vitamins.

► Discuss the general use of food supplements. Compare fresh and processed foods, and children and adults – are supplements needed? Are any safety issues raised?

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Fungi and Disease

#

Recap. . . . . .

Bacteria, fungi and viruses are all **micro organisms**. We learnt last lesson that some fungal species are beneficial to humans in the food industry and in medicine production.

However, some fungal species can cause disease along with bacteria and viruses. Micro organisms that cause disease are called **pathogens**.

Let's Focus on Fungi

Certain fungi have the ability to cause diseases in humans, plants and animals.

When looking at plant pathogens it's important to remember that some parts of the plant are above ground – stems and leaves and other parts are below ground – roots. So, it makes sense that airborne pathogenic fungi infect the stems and leaves and soil borne pathogenic fungi infect plant roots.

Plant diseases have some very strange names! They are given names like:

- Blights
- Rusts
- Smuts
- Mildews

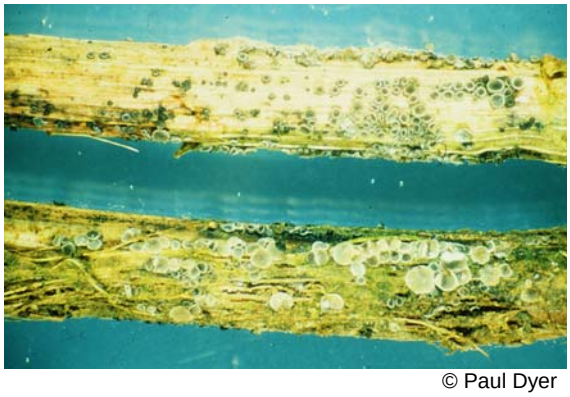
Most of these names come from old descriptions of the effect on the crop and were given to the disease long before its cause was known. Mildew is a cottony covering on the leaf (on which dew forms readily). A crop that looks sick and dying might be described as being 'blighted'; plants covered in red masses (actually fungal spores) as being 'rusted'; or if covered in black deposits (spores again) like soot, then it's a 'smut' or a 'tarspot'.

Some Examples of Plant Diseases

#

This is a tarspot disease of sycamore leaves. Caused by a fungus called *Rhytisma acerinum* which is very common and widely distributed. You can see this on sycamore leaves throughout the year.

© David Moore



© Paul Dyer

This is 'eyespot' disease on wheat stems, caused by a fungus with the wonderful name of *Pseudocercosporella herpotrichoides*. It's a serious disease of cereals because it survives from year to year on stubble debris, and can even survive being ploughed under and ploughed up again the following season.

This is the rust disease of wild and cultivated daisies caused by *Puccinia distincta*. An epidemic of this disease started in the mid-1990s and spread from Australia, through Europe, and into North America. In many places, ornamental daisies can no longer be grown unless they are protected by fungicide sprays.

© Roland Weber

Human diseases caused by fungi are called **mycoses**. The diseases are divided into three groups depending on where they occur on our body. These groups are:

Superficial ►	These infect the skin, nails and hair.
Subcutaneous ►	These infect the deep layers of the skin.
Systemic ►	These are the most severe fungal diseases. An unsuspecting person may inhale the pathogenic fungal spores. Some spores stay in the lungs and grow while others enter the bloodstream, travel around the body and infect other organs.

Most fungal infections are due to opportunistic pathogens; these affect people who are already ill or have a suppressed immune system (e.g. in patients who have been given an organ transplant, or in AIDS patients). In a perfectly healthy person the fungus would not normally cause disease. True pathogens can cause disease in even the healthiest person.

Like bacteria, fungi can produce toxins. Fungal toxins are called **mycotoxins** and the diseases they cause are called **mycotoxicoses**. Several food items are particularly susceptible to fungal disease including bread, dried pasta, peanuts and stored grains and cereals. All of these are dry foods which should be stored in dry conditions. When stored in the wrong conditions of high temperature and high humidity, mycotoxins can be found as a result of fungal ('mould') growth in the stored material.

The most widespread and dangerous of these are the **aflatoxins** produced by the mould called *Aspergillus flavus*. These are carcinogenic, which means they can cause cancer. Aflatoxins pose a serious threat to both humans and domestic animals because the mould grows on poorly-stored grain and animal feed. When eaten, the toxin is stored in the liver where it can eventually cause hepatitis and liver cancer.

Some Examples of Human Diseases

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Ringworm is not a worm, but a common fungus infection of the skin. The fungus (often one called *Microsporum*) does not invade living tissue but the fungus and its metabolic products cause inflammation. This 5-week old baby caught the disease from contact with the family's pet cats.#

Image courtesy of www.doctorfungus.org © 2005#

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Epidermophyton floccosum causes athlete's foot in humans – usually in the web area between toes – and is common in shoe-wearing people because it's favoured by warm, humid conditions. It can also affect the hand and other areas of the body, and here is attacking toe-nails.#

This is a *Madurella* mycetoma on a patient's limb. This disease occurs all over the world, but is most common in tropical and sub-tropical regions. It is caused by a number of fungi including *Madurella*, *Acremonium*, *Curvularia*, *Fusarium* and *Aspergillus*.#

Image courtesy of www.doctorfungus.org © 2005

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These are skin ulcers of a patient suffering from blastomycosis (caused by *Blastomyces dermatidis*). The disease starts in the lungs when spores are inhaled, and then spreads to other organs.

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History Lesson!

An important example that demonstrates just how devastating pathogens of our crops can be is the **Irish Potato Famine** of 1845 - 46.

The organism responsible was a relative of the fungi called potato blight or *Phytophthora infestans* – even the scientific name means 'infesting plant destroyer'! The whole of Europe was affected with the disease (which was introduced on plants imported from the Americas) but Ireland suffered more because the poorest people lived entirely on a diet of potatoes. English labourers were less affected because they had cereal foods in their diet and cereal crops were not affected by the disease. For the majority of the Irish, though, if there were no potatoes they starved. Sadly, from 1845 to 1860 a staggering 1 million people died as a direct consequence of the famine, and over 2 million emigrated (many to the USA).

So what can we learn from this tragic incident?

- Grow more than one crop. Growing a single crop plant over vast areas (called monoculture) encourages disease to spread rapidly. Also, populations should not be entirely dependent on a single source of food.

- Use of fungicides will prevent or at least control disease. Of course, in the mid-nineteenth century the cause of 'potato blight' was not known because the 'germ theory' of disease (that is, the idea that diseases are caused by infections) had not even been suggested in 1845.

- Store in the correct conditions: this means proper control of humidity, oxygen and temperature. It doesn't have to mean high technology – what's required is good aeration and careful protection from rain and ground water.

- Weather conditions play in important part in the spread of crop disease.