**Asexual vs sexual reproduction compared**

| | Asexual reproduction | Sexual reproduction |
|---|---|---|
| Parents | Requires only one parent organism | Requires two parent organisms |
| Genetic outcome | Offspring are generally identical to the parent, so diseases are passed on and adapting to new conditions (i.e. evolution) is very slow | Produces genetic variation in offspring, so the species is more able to adapt to different environments; a population may be more resistant to disease |
| Time and energy | Time and energy efficient, e.g. no need to find a mate | Requires more time and energy, e.g. need to find a mate |
| Population growth | Population can increase rapidly when conditions are good | Generally much slower because more time / energy is required; only half the population can reproduce |

**Pause and reflect:** high-quality food is beneficial for sexual reproduction; low-quality food is beneficial for asexual reproduction.

### Fission

- Found in all domains and all kingdoms of life; occurs in unicellular and multicellular organisms.
- A parent cell / organism divides itself into equal parts.
- **Binary fission** results in two cells / organisms (common in bacteria and archaea).
- **Multiple fission** results in more than two cells (common in Protista).

### Budding

- Found in all domains and all kingdoms of life; occurs in unicellular and multicellular organisms.
- A parent cell or organism divides itself into two **unequal** parts: a small bud (outgrowth) forms on the parent and breaks off to form a new daughter cell / organism. Example: yeast (Fungi).

### Fragmentation

- Found in all eukaryote kingdoms of life (Fungi, Animalia, Plantae, Protista); occurs in multicellular organisms.
- Fragments of an organism can break off and become a new organism.

### Vegetative propagation

- Found only in Plantae; occurs in multicellular organisms.
- A new plant grows from a fragment of the parent plant.
- Different strategies: runners, bulbs, tubers, suckers, basal shoots, root sprouts. Examples in the notes: potato, pitcher plant.

# Lecture 2: Respiration

## Why does life respire?

- Respiration is the process by which an organism exchanges gases between itself and the environment.
- All species (unicellular and multicellular) respire to release energy from their food to fuel cellular processes.
- Different organisms have different structures and mechanisms to respire.

## Mechanisms of respiration

Organisms extract energy from food via:

1. **Aerobic cellular respiration**: uses oxygen to extract energy from food.
2. **Anaerobic cellular respiration**: does not use oxygen but a different compound (e.g. nitrate or sulphur).
3. **Fermentation**: anaerobic degradation of a substance, e.g. glucose, to smaller molecules (lactic acid / alcohol) with extraction of energy.

Note: fermentation does not use the electron transport chain, so it is not considered respiration.

## Benefits of aerobic and anaerobic respiration

- **Aerobic**: releases more ATP molecules than anaerobic respiration; allowed the evolution of multicellularity and larger organism size.
- **Anaerobic**: releases energy quickly; can occur in low-oxygen environments.

## How did respiration evolve?

- Timeline figure: first life (~4 billion years ago), photosynthetic bacteria (which produce a large amount of $O_2$), then **aerobic respiration** (~3 billion years ago), the origin of eukaryotes, multicellular eukaryotes, meiotic sex and the present day.
- A second graph plots atmospheric $PO_2$ (atm) against billion years ago, marking the **Great Oxygenation Event** (the rise in atmospheric oxygen) between its first two stages, with a further rise later in the record.

## Where did mitochondria come from?

- Mitochondria evolved via **endosymbiosis**: a host cell engulfed a prokaryote cell (part of the endosymbiotic theory).
- Two hypotheses about the organisms involved:
    a. **Traditional view**: a eukaryote host engulfed an aerobic prokaryote.
    b. **Alternative view**: a prokaryote host engulfed a facultative anaerobic respiring prokaryote.

## Testing observed vs expected genotype frequencies

*How can we tell if observed genotype frequencies differ from those expected under Hardy–Weinberg equilibrium (HWE)?*

1. **Calculate allele frequencies** using the population genotypes. Worked example (n = 200): observed BB = 110, Bb = 60, bb = 30 (frequencies 0.55, 0.30, 0.15). p = (0.55 + ½ × 0.30) = 0.7; q = (0.15 + ½ × 0.30) = 0.3.
2. **Use the Hardy–Weinberg equation** to calculate the expected genotype frequencies (the null hypothesis): expected BB = $p^2 \times 200 = 0.49 \times 200 = 98$; Bb = $2pq \times 200 = 0.42 \times 200 = 84$; bb = $q^2 \times 200 = 0.09 \times 200 = 18$. (The initial frequency of the alleles is the same in observed and expected.)
3. **Apply a simple chi-squared test**: $\chi^2 = \Sigma (O - E)^2 / E$, where O = observed and E = expected.

| Genotype | Observed (O) | Expected (E) | $(O - E)^2 / E$ |
|---|---|---|---|
| BB | 110 | 98 | 1.47 |
| Bb | 60 | 84 | 6.86 |
| bb | 30 | 18 | 8.00 |
| Total | 200 | 200 | $\chi^2 = 16.33$ |

4. **Check whether the $\chi^2$ value is significant.** For allelic data, degrees of freedom (d.f.) = n − 1, where n = number of alleles [two alleles, so d.f. = 1]. Compare $\chi^2$ with the critical-value table (for 1 d.f.: 3.84 at P = 0.05, 6.63 at P = 0.01, 10.83 at P = 0.001). $\chi^2 = 16.33 > 10.83$, so **P < 0.001**: the observed genotype frequencies differ significantly from HWE

## Lecture 14: Metabolism, scale and the individual

### Scale in biology

- Nanometre to micrometre = molecular; micrometre to metre = individual; millimetre to kilometre = population / community; millimetre to kilometre = ecosystem (figures from Knox, Fig. 31.17 and Fig. 45.19).

### The individual as a thermodynamic system

- The organism wants to attain **homeostasis**. Metabolism is where different materials and substances come together; evaporation occurs from a hot, wet surface.
- Energy in = energy out; matter cannot be destroyed (figure: micro and macro scales of feeding, metabolism and heat loss; Knox).

### Measuring metabolic rate

- **Direct calorimetry** = heat measurement. $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$ + energy + heat (673 Cal, 2820 kJ per mol).
- **Indirect calorimetry** = gas measurement: the method by which the type and rate of substrate utilisation and energy metabolism are estimated *in vivo* from gas exchange measurements ($CO_2$ production and $O_2$ consumption during tests and steady-state exercise).

| Measure | Applies to | Conditions |
|---|---|---|
| **Basal metabolic rate (BMR)** | Birds and mammals (endotherms) | Not moving; not digesting; in the thermoneutral zone (not feeling cold or hot); in the inactive phase; an adult; not reproducing |
| **Standard metabolic rate (SMR)** | Ectotherms | Not moving; not digesting; at a known temperature; in the inactive phase; an adult; not reproducing. Difference from BMR: BMR requires the thermoneutral zone |
| **Resting metabolic rate** | Any | Not moving; not digesting; in the thermoneutral zone; no requirement for the active / inactive phase; an adult; may be reproducing |
| **Field metabolic rate** | Free-living animals | Measured with doubly labelled water |

### Temperature and metabolic rate

- **Homeothermic** (constant temperature): **endotherm** – generates heat to raise body temperature above ambient (figure: body temperature stays constant across ambient temperatures of 0–45 °C while metabolic rate changes).
- **Heterothermic** (variable temperature): **ectotherm** – body temperature varies with ambient temperature (figure: body temperature rises with ambient temperature).

## Physiological thermoregulatory responses

- **Metabolism** (all endocrine here): *non-shivering thermogenesis* (sympathetic regulation, endocrine; brown adipose tissue, BAT) and *shivering thermogenesis* (somatic regulation).
- **Skin blood flow** (sympathetic): vasoconstriction (cold defence) and active vasodilation (heat defence).

| Response | Cold defence | Heat defence |
|---|---|---|
| Non-shivering thermogenesis (BAT) | Activated | Inhibited |
| Skin blood flow | Vasoconstriction | Vasodilation |
| Water evaporation | Inhibited | Sweating, panting, saliva spreading |
| Shivering thermogenesis | Activated | Inhibited |
| Postural changes | Reduce exposed surface | Increase exposed surface |
| Behavioural choice | Heat-seeking | Cool-seeking |
| Altering microenvironment | Nesting, social huddling | Air conditioning |

## Elements of a reflex pathway

- **Stimulus → sensor → afferent → control centre / integration → efferent → effector → response.** The variable under regulation is the stimulus.
- **Reflex response to changes in environmental temperature**: skin sensors detect a change in ambient temperature; afferent signals go to homeostatic regulatory centres (unconscious; brain temperature is a target) and, via higher centres in the brain, lead to behavioural responses (conscious awareness) until thermal comfort is restored.
- *Body temperature falls*: blood vessels constrict so heat is conserved; sweat glands do not secrete fluid; shivering (involuntary contraction of muscles) generates heat, which warms the body (negative feedback). *Body temperature rises*: blood vessels dilate, resulting in heat loss to the environment; sweat glands secrete fluid, and as the fluid evaporates heat is lost from the body (negative feedback). Both return the body to normal body temperature.

## Homeostasis: thermoregulation (the hypothalamus is the control centre)

- **Increased body temperature** (e.g. when exercising or the climate is hot): the hypothalamic set point detects warmer blood and activates the heat-losing centre, so skin blood vessels dilate (capillaries become flushed with warm blood; heat radiates from the skin surface) and sweat glands are activated.
- **Decreased body temperature**: blood is diverted from skin capillaries and withdrawn to deeper tissues; the hypothalamus activates the heat-promoting centre; skeletal muscles are activated when more heat must be generated and shivering begins.

**Heterotrophs: diversity of mouthparts (invertebrates)**

- Invertebrates have evolved perhaps the greatest diversity of mouthparts.
- They spend a disproportionate amount of their lives as juveniles, accumulating the resources needed for producing offspring as adults.
- The mouthparts and feeding strategies of the adult and juvenile stages of an insect can be very different; some insects do not feed at all as adults.
- Mouthpart types shown: chewing, piercing / sucking, carving, siphoning, sponging.

**Heterotrophs: the evolution of jaws (vertebrates)**

- The earliest fish were jawless; jaws derived from gill arches, and teeth evolved soon after jaws.
- The evolution of jawed fish is linked to declines of marine invertebrates, e.g. trilobites.

**Heterotrophs: evolution of teeth (vertebrates)**

- **Homodonts**: all teeth are the same shape; typical of non-mammalian vertebrates including sharks and reptiles
- **Heterodonts**: have a variety of tooth shapes; typical of mammals, which mostly have incisors, canines, premolars and molars; teeth are further modified depending on ecology.

**Heterotrophs: big jaws**

- Dragon fish can eat prey as big as themselves: there is a space between the brain case and vertebrae, and this gap allows the head to tip back during feeding.
- Dragonfly larvae have hinged mouthparts that are folded away and extend and retract during feeding.

**Check your understanding**

- *Why might insect mouthpart diversity have evolved?* Insects colonised the land and lived in a variety of environments with different species to feed on; modifications allowed them to exploit a diversity of prey types and reduce competition between species.
- *Why did fish with teeth evolve rapidly after jawed fish?* Once jaws had evolved there was a structure to support teeth; jaws gave a selective advantage (e.g. crunching hard exoskeletons) but jaws plus teeth gave a greater one, allowing them to outcompete and eat jawed but toothless species.
- *Would a bearded dragon (reptile) be holodont or heterodont?* Homodont (written "holodont" in the notes).
- *Why is mouthpart diversity critical to the success of aquatic and land animals?* It allows different species to exploit different groups of species in different environments.