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2018 HIGHER SCHOOL CERTIFICATE
COURSE MATERIALS

HSC Biology

Maintaining a Balance

Term 3 – Week 11

Name …….

Class day and time ……

Teacher name ……...

Term 3 – Week 11 – Theory

- **Outline the role of the nervous system in detecting and responding to environmental changes**

HOMEOSTASIS

HOMEOSTASIS AND NEGATIVE FEEDBACK IN THE BODY

As you can see from the air conditioner model discussed last week, there needs to be a method of sending messages from one component to the next in a negative feedback system. One system involved in every single one of the myriad of negative feedback systems in the body is the nervous system. The reason is it is the communication system, as well as the control centre, of the body. The nervous system is so named because it is made of neurons, or nerve cells, which transmit messages in the form of electric impulses.

- A neuron is either transmitting electrical impulses ('on') or it is not ('off'). For instance, the pressure receptors in your skin are neurons, but when there is no pressure, they are not sending any impulses. The brain interprets the absence of electrical impulses as meaning there is no pressure. When pressure is applied to them, they start firing electrical impulses, which your brain interprets to mean "pressure is being applied".

THE NERVOUS SYSTEM ITSELF IS COMPRISED OF TWO DIVISIONS

The Central Nervous System (CNS) consists of the brain and spinal cord. The brain is the "control centre" of the body and processes feedback from various receptors. It then integrates a response and sends a message back out to the body. One region of the brain that is particularly involved in homeostasis is the hypothalamus, which controls many negative feedback systems in the body.

The spinal cord is a bridge between the brain and the neurons of the body. All impulses to and from the brain must pass through the spinal cord. For instance, the pressure receptors in the previous example will send their messages, via nerves, to the spinal cord. The spinal cord will then carry the message to the brain for processing. The brain then sends a response message which must be carried to effectors in the body, and so it is transmitted down the spinal cord to the body.

The previously mentioned "neurons of the body" are all the nerve cells outside (i.e. not part of) the CNS and comprise the Peripheral Nervous System (PNS), the major communication system of the body. The peripheral nervous system itself is composed of two subdivisions:

- The **sensory** or afferent component carries messages **to the brain from the body** and is responsible for detection/sensation of internal and external conditions. Sensation requires a receptor (often a specialized nerve cell) which sends impulses via sensory nerves to the brain, which interprets the messages. For instance the pressure receptor sends its message to the brain via sensory nerves
- The **motor** or efferent component is nerves which carry messages **from the brain** to the body and subsequently to different organs/tissues of the body, eliciting a response from them. The tissues/organs that motor nerves stimulate are the effectors of the body. For instance, when you want to move, the message is carried from the brain to the muscles via the motor component of the PNS

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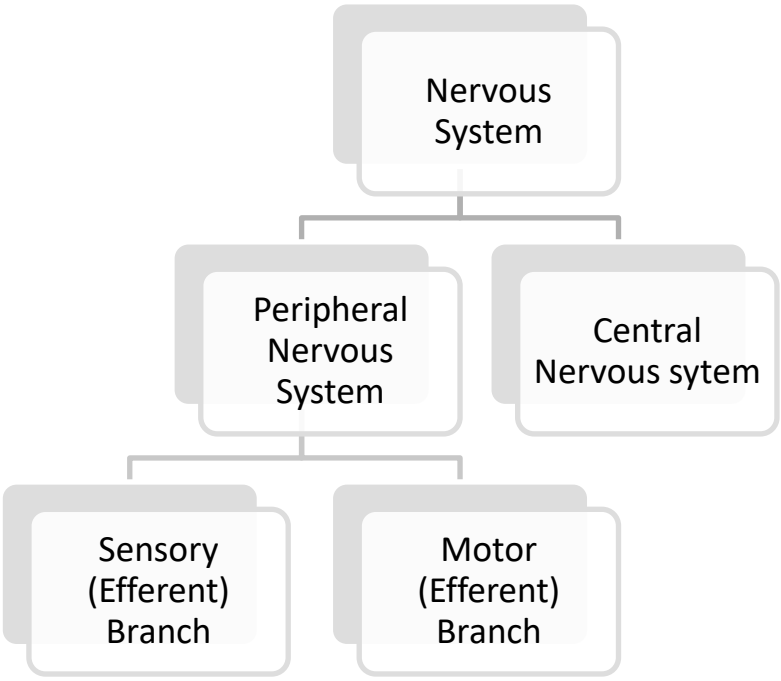

In summary, the nervous system is largely responsible for

- Detecting any changes from the normal state (using receptors) and transmitting this information to the brain (via sensory nerves)
- Processing the information and initiating a response message (the brain/hypothalamus)
- Counteracting the change by activating an effector (via the motor component of the PNS)

Hence, the nervous system is crucial in homeostasis.

To clarify this, examine thermoregulation in the human body. Thermoregulation is the regulation of temperature and, as endothermic organisms, our body temperature is controlled quite stringently so that it lies in the optimal temperature range of between 36.6 and 37.2℃. .

- This set point is maintained in the hypothalamus (CNS)

When you burn yourself, the heat is detected by **thermoreceptors**. These are specialized nerve endings that respond to temperature. Since they lie outside the CNS, they are part of the PNS

- There are two types: heat receptors, which detect an increase in temperature, and cold receptors which detect a decrease in temperature.

Since they are the receptors in this homeostatic system, they transmit messages to the brain via the sensory nerves.

The effectors in the thermoregulatory system are quite varied. They include

- Sweat glands: these produce sweat which cools the body by evaporation
- Skin hairs: these trap heat when erected, helping to keep the body warm
- Thyroid gland: release of thyroid hormones by the thyroid gland increases metabolic rate (the rate of biochemical reactions, such as respiration) generating more heat

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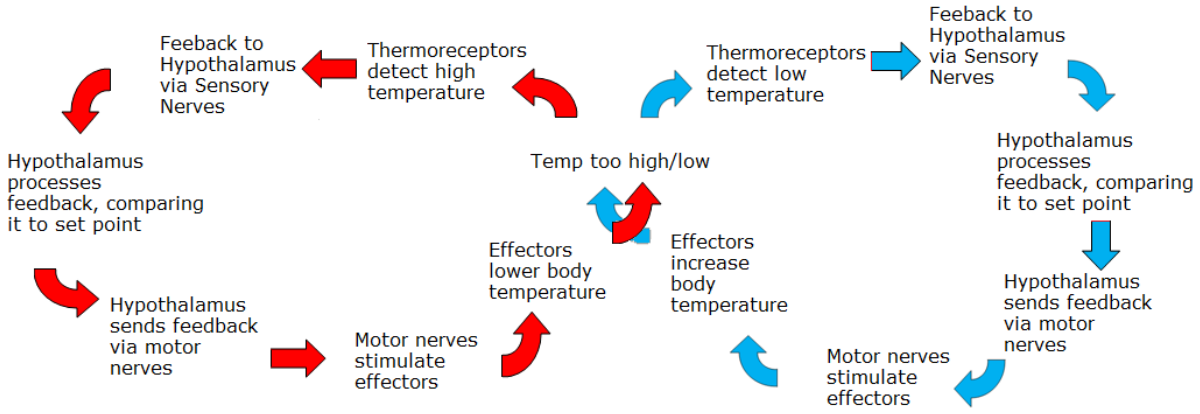
- Muscular shivering: when muscles contract, they generate lots of heat, which is how shivering (very rapid muscular contraction) helps to heat the body. This can be considered an increase in metabolic rate of the muscles (endothermic organisms, by definition, are able to regulate their temperature by altering metabolic rate)
- Blood vessels in the skin which can constrict (get thinner) or dilate (get wider)
    - When blood vessels constrict (vasoconstriction), there is less surface area through which to lose heat to the air from the blood. This decreased heat loss helps to conserve heat
    - When blood vessels dilate (vasodilation), there is greater surface area through which to lose heat. This increased heat loss helps to cool the body

The following flow chart summarises thermoregulation in the human body



It should be noted that while negative feedback is by far the most common form of feedback in the body, there is another mechanism known as positive feedback. Negative feedback involves counteracting changes to the normal state, so unsurprisingly positive feedback involves reinforcing changes instead. The most well known example of this is during the birthing process in which the contractions that expel the baby are caused by the release of the hormone oxytocin.

1. The initial contraction push the baby's head against the cervix
2. The pressure against the cervix is detected by receptors which stimulate the release of oxytocin
3. The oxytocin stimulates further contractions
4. The contractions push the baby's head against the cervix, reinforcing the cycle

Positive feedback is relatively rare, another example being the entry of sodium into nerves during action potentials.

- **Compare responses of named Australian ectothermic and endothermic organisms to changes in the ambient temperature and explain how these responses assist temperature regulation**
- **Analyse information from secondary sources to describe adaptations and responses that have occurred in Australian organisms to assist temperature regulation**

ECTOTHERMS

Ectotherms are the organism which in layman's terms is referred to as "cold blooded". This is a rather misleading name, as the body temperature of an ectotherm is, by definition, dependent on the outside temperature.

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- Ectotherms are organisms which depend on external sources to gain body heat. This is why they are also known as exothermic (exo = outside, thermos = temperature), as they gain heat from their surroundings.

Reptiles are the most commonly known ectothermic organisms, but other examples include insects, amphibians and fish. The nature of ectothermy means the body temperature of an ectotherm varies depending on the temperate of their environment.

- This is called **poikilothermy**

The environment influences body temperature of any organism in a number of ways

- **Radiation**: heat is lost to the environment from the surface of an organism in the form of infra-red radiation. External radiation may also be absorbed to increase body heat
- **Conduction**: this is the transfer of heat between particles that are in contact with each other. For example, an organism may gain or lose heat to the ground (depending on which is hotter) as it is in direct contact with the ground
- **Convection**: this is a special case of conduction where the heat is transferred to a gas or a liquid. The heating of air by your body, for instance, causes it to rise away from your body, carrying the heat away with it. At the same time, cooler air sinks and comes in contact with the body, becoming heated and rising away from the body. This process repeats, allowing a gas or liquid to continually cool a body by this flow of fluid, known as convection. Liquids, especially water, are particularly good at cooling by convection
- **Evaporation**: water on the skin is heated by the body and eventually evaporates, taking the body heat with it as it vapourises and leaves the body. Water is able to absorb a lot of heat as it evaporates, making it an excellent evaporative coolant

This presents an obvious problem for ectotherms: external temperatures may not always be optimum for an organism's biochemistry and metabolism.

- This is not a major issue for aquatic organisms, as the temperature of large bodies of waters stays remarkably constant, due to the high specific heat of water. Thus, their metabolic processes need only be adapted to function optimally at the average temperature of the water and they will, on average, be able to operate at optimal efficiency. This is why the vast majority of aquatic organisms are ectothermic

The downsides of ectothermy are significant for terrestrial animals, however, as terrestrial temperatures can fluctuate wildly due to a number of different factors, the most obvious of which being the day/night cycle. This is particularly important in Australia, where temperatures during the day may be searing, while at night they may be extremely cold. Hence, terrestrial ectotherms must find ways of ensuring their body temperature stays within a suitable range, a goal which they achieve using a number of adaptations, most of which are behavioural.

Adequate heat is necessary for the body's metabolism to proceed at a sufficient rate, so ectotherms have evolved behaviours allowing them to gain as much heat from their environment as safely possible:

- **Sunbaking** is the classic example – reptiles especially will sit in the sun early in the morning. This increases their body temperature by absorption of solar radiation. Remember that radiation is absorbed/released from the surface of an organism, so in order to maximise the absorption of the sun's rays, many reptiles will flatten themselves out, maximising their surface area available to the sun

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- **Flattening their body** out serves another purpose: it increases conduction heating from the sun heated surface that the organism is in contact with. This is particularly true for rocks at the end of the day, as they can be quite warm – even hot – and they retain this temperature for extended periods of time, allowing ectotherms to harness the sun's heat even when it is not longer present directly.
- When conditions become too cold, and there are no adequate sources of heat to utilise, many ectothermic organisms have evolved the ability to enter a state known as **torpor** (reptiles) or diapauses (insects). In this state, metabolism slows down to the bare minimum and they go into a state similar to hibernation. If outside temperatures are particularly low, they may produce biological antifreezes, which prevent their fluids from freezing. Once conditions improve (i.e. get warmer) they can reawaken.

On the other side of things, excessively high temperatures are extremely detrimental to an organism's metabolic pathways, so there are also behaviours which minimise heat gain. Particularly in the desert, as the day progresses, the outside temperature increases and the sun's intensity increases, so eventually it becomes detrimental for ectotherms to be out in the sun, as they will overheat.

- Hence, many have evolved shade-seeking or burrowing behaviours. Burrowing is particularly effective as the temperature in burrows can stay remarkable constant This is because the soil around the burrow is not in direct contact with the sun during the day, so it doesn't get extremely hot, however there is enough conduction of heat through the soil so that at night the soil is significantly warmer than the air temperature.
- One way of avoiding dangers of the searing daytime temperatures in deserts is to evolve nocturnal behaviour. While temperatures can drop to sub-zero at night, they tend to be less extreme at dusk and dawn, so many ectotherms are active at these times

Structural Adaptations tend to play a less significant role in ectotherms.

ENDOTHERMS

Endotherms are defined as organisms which are able to regulate their internal temperature through their internal metabolism. Thus, their temperature is an example of homeostasis and they are referred to as homeotherms. Unlike ectotherms, they have a wide variety of structural and physiological adaptations on top of their behavioural adaptations (which tend to be similar to those of ectotherms) which allow them to maintain their constant temperature:

CONTROL OF BLOOD FLOW:

- **Subcutaneous capillary networks**: These are networks of blood vessels just below the skin. These networks allow them to control the amount of heat is lost by conduction/convection (and also evaporation when combined with sweating). In high temperatures, endotherms will employ vasodilation, or widening of blood vessels, to increase the surface area through which to lose heat. Conversely, when it is cold and they need to conserve heat, they will constrict (narrow) the blood vessels to minimize heat loss. For example, the ears of elephants (and many large eared mammals, such as the bilby) as well as the forearms of kangaroos have dense capillary networks.
- **Shunts**: this is an extreme form of blood flow control where blood flow to particularly cold extremities can be cut off almost completely to minimize heat loss. For example, penguins do this to minimize heat loss through the feet to the ice.

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- **Countercurrent blood flow**: by having arteries and veins adjacent to each other, the countercurrent blood flow (blood flowing in opposite directions) allows many aquatic mammals, such as whales, to reduce cooling of their internal organs by increasing the temperature of venous blood (as heat moves from the water arterial blood to the cooler venous blood).

EVAPORATIVE COOLING

- Due to the high specific heat of water, evaporation of water is a particularly effective method of losing heat
    - **Sweating**: this is the most well known form of evaporative cooling, where water is released by sweat glands in the skin when temperatures are high. This is employed by humans and some other mammals, such as horses
    - **Panting**: this allows evaporative cooling from the mouth and is utilized by animals for whom sweating isn't effective, usually due to the presence of thick fur
- **Insulation**: fur, feathers and fat deposits (blubber) are very effective at insulating the body against extremes. For instance, in cold weather, mammals will erect their hairs, trapping warm air to keep them warm.
    - In many animals, fur and fat grow in preparation for colder months
    - Shiny fur may also help to reduce heat gain in hot climates by reflecting solar radiation, reducing its absorption by the skin

METABOLIC REGULATION

- **Shivering**: this well known reaction to the cold relies on the generation of large amounts of heat due to muscle activity.
    - Conversely, animals will reduce temperature gain in hot weather by remaining still, in order to prevent muscular heat generation
- **Thyroid hormone-mediation metabolic regulation**: the thyroid hormones, released by the thyroid gland, control the rate of cell metabolism. Biochemical reactions, especially respiration, invariably release a significant amount of heat as a by-product. Thus by controlling the amount of thyroid hormones release, cell metabolism and its heat generation can be controlled.
- **Hibernation**: the endotherm equivalent of torpor, hibernation relies on the same principle of 'waiting out' the colder months with the minimum metabolic rate to minimize energy expenditure

It should also be noted, that body shape is important in thermoregulation, particularly surface area to volume ratio:

- In hot climates, animals tend to be smaller, with longer limbs and larger ears, giving them a higher surface area to volume ratio. This allows them to maximize the surface area they have through which to lose heat.
- In cold climates, animals tend to be larger, with rounded bodies and short limbs. This yields a lower surface area to volume ratio, which in turn minimises the heat loss to the environment

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COMPARING AN AUSTRALIAN ECTOTHERM AND ENDOTHERM

The thorny devil (lizard – ectotherm) and red kangaroo (mammal – endotherm) are two iconic Australian animals well adapted to dealing with the desert heat. The following table compares their methods of dealing with their environment:

Kangaroo	Thorny Devil
• **Fur**: helps to reflect solar radiation, insulating them against the heat • **Blood vessel distribution**: dense networks of blood vessels are found in the forearm; these can be dilated or constricted to maximise or minimise heat loss • **Licking**: they will like the fur of their forearms to add the effects of evaporative cooling to the forearm blood vessels • **Sweating**: evaporative cooling (although less effective due to fur) • **Body shape**: long, skinny legs and large ears increase the surface area through which to lose heat • **Movement**: hopping is an extremely efficient method of movement which maximises distance whilst minimising muscular heat generation. • **Shade seeking**: Kangaroos will seek shade and minimise movement during the hottest parts of the day	• **Diurnal**: active before midday and in the afternoon to avoid temperature extremes • Very little activity during coldest months (August – December) or hottest months (January, February) • **Basking**: they bask in the mornings and afternoons; they also press themselves against the sand to minimise conductive heat gain • Raise themselves on their legs during the day to maximise convective heat loss through the air and minimise conductive heat gain through sand • Burrowing and shade seeking: behaviour that manifests at the hottest times of the day and during the cold nights • **Slow movement**: slow, rocking motion reduces muscular heat generation

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Term 3 – Week 11 – Homework

- **Outline the role of the nervous system in detecting and responding to environmental changes**

1. Identify the name of the process which can be described as "detecting and responding to environmental changes". **[1 mark]**

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2. Complete the following table explaining the roles of the nervous system in homeostasis. **[3 marks]**

Component	Role	Nervous system equivalent
Detector		
Processor		
Effector		

3. Identify and describe the two subdivisions of the nervous system **[2 marks]**

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- **Compare responses of named Australian ectothermic and endothermic organisms to changes in the ambient temperature and explain how these responses assist temperature regulation**
- **Analyse information from secondary sources to describe adaptations and responses that have occurred in Australian organisms to assist temperature regulation**

1. Define the terms 'ectotherm' and 'endotherm'. **[2 marks]**

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2. Outline the ways in which the environment can affect the temperature of an organism. Provide examples in your answer. **[3 marks]**

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Evaluate the statement "Ectotherms are affected by external temperature variation, endotherms are not." **[3 marks]**

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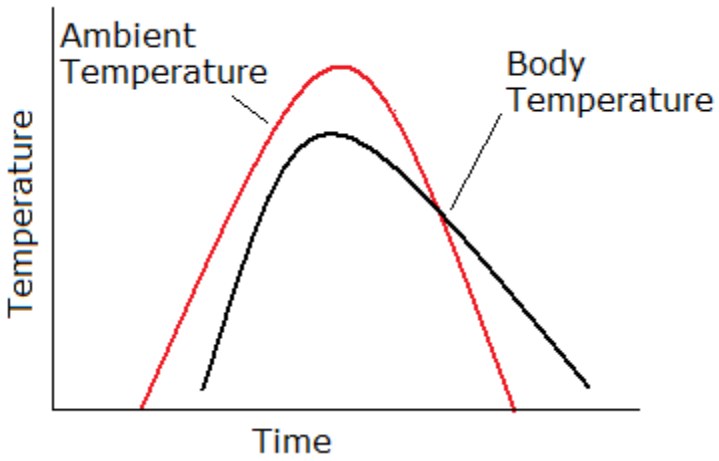
Consider the following diagram:



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a. The graph above describes the body temperature variation of an ectotherm. Justify this conclusion. **[2 marks]**

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b. Draw a graph of that represents the temperature of an endothermic organism as the day progresses. **[2 marks]**

3. Discuss the advantages and disadvantages of being an ectothermic organism. **[3 marks]**

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4. Most aquatic organisms are ectothermic. Account for this. **[4 marks]**

5. Identify an Australian endothermic organism and evaluate how it has adapted to deal with the Australian climate. **[5 marks]**

6. Discuss how a named exothermic organism is able to survive in the Australian climate. **[5 marks]**

End of homework

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