BIOL 454

ENVIRONMENTAL PHYSIOLOGY

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COURSE OUTLINE

- Principles of Homeostasis
- Adaptation
  - Adaptation to special environments
    - Desert region
    - Cold region
    - High altitude
    - Aquatic environment

  - Hibernation
  - Aestivation
  - Diapause
- Water and Osmoregulation
- Buoyancy and diving
- Respiration and Excretion
- Biological rhythms

REFERENCES

- Knut Schmidt-Nielsen (1990) Animal physiology-adaptation and environment 4th edition

✓Several general biology textbooks

What is Environmental Physiology?

- It is the branch of biology that deals with how organisms use their physiological mechanisms to respond and adapt to changes in environmental conditions.
- How biological functions of an organism relates to their environment.
- the study of physiological adaptation or adjustment to the environment

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ENVIRONMENT

•Aggregate of surrounding things, conditions or influence.

- **ASPECTS OF THE ENVIRONMENT**
- Light
- Temperature
- Water
- Altitude

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- The environment, however, is rarely constant even over the *short-term*.
- Temporal Variation : daily and seasonal variation exist in many environmental factors (e.g., light, energy, temperature, moisture) and animals must respond to this variation in order to survive and reproduce .
- Spatial Variation : multitudes of habitats and microhabitats exist, even within a given environment or geographic area.
- Animals occupy most of the available habitats throughout the world, so they must show a wide variety of physiological adaptations allowing them to inhabit the conditions present.
- Many of these habitats and microhabitats are potentially stressful to the organism, at least at times

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- **PLANTS**
- **LIGHT**
- Leaf area
- Day length sensitivity
- Reflection
- Transmission
- **TEMPERATURE**
- Open stomata
- Evapotranspiration
- Wilt

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- **ANIMALS**
- Light (photoperiod or day length)
  - Pineal gland
  - Reproduction and mating behaviour
    - Birds
    - Sheep
    - Large ungulates (rutting, heat)
  - Feeding behaviour
  - Hibernation
  - Antler growth

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HOMEOSTASIS

- Cells of the body are designed to serve a purpose/role
- These specialized cells function are possible only when extracellular conditions are kept within limits(narrow limits)
- Conditions as concentration of Oxygen, glucose e.t.c. must be held constant for cells to function efficiently and interact properly with others
- Conditions within an organism is dynamic-fluctuating continuously within narrow limits

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- *Cells within the body must remain bathed in fluid that offers nutrients and carries away metabolic wastes.*
- *The fluid around the cells is* **extracellular fluid**.
- *Much of it is* **interstitial**-*it occupies spaces between cells and tissues. The remainder is* **plasma**-*fluid portion of blood*
- *Interstitial fluid exchanges substances with cells it bathes and with blood.*

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- Each cell of the animal body engages in basic metabolic activities that ensure its own survival
- The cells of a given tissue perform one or more activities that contribute survival of the whole organism.
- *The component parts of every animal work together to maintain the stable fluid environment that all of its living cells require*

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- The combined contributions of individual cells, tissues, organs and organ systems that are engaged in a division of labor help maintain a stable internal environment.

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- **HOMEOSTASIS**
- The tendency of a physiological system to maintain internal stability owing to the coordinated response of its parts to any disruptive stimulus

- **HOMEORHESIS**
- The coordinated response of a physiological system to support a new or altered physiological state.

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Principles of Homeostasis

- **HOMEOSTASIS** is a state in which the vertebrate body maintains relatively constant internal conditions for proper functioning of body systems

- The state in which physical and chemical aspects of the internal environment (blood, interstitial fluid e.t.c.) are being maintained within ranges suitable for cell activities.

- Homeo⟶ same; stasis⟶ standing still

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- All the systems of the human body are involved, with particular contributions by the endocrine, nervous, respiratory, and renal systems

- Once homeostasis is maintained, an organism is generally said to be healthy.

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- An organism is said to be in a state of homeostasis when its internal environment;
  - Contains the optimum concentration of gases, nutrients, ions and water
  - Has the optimum temperature
  - Has the optimum pressure for the health of the cells

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- Homeostasis is essential for life and most of the mechanisms not devoted to reproduction are concerned with maintaining homeostasis.
- When it is disturbed ill health may result
- If body fluids are not eventually brought back into balance, death may occur

Why the routine examinations?

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- Homeostasis in all organisms is disturbed by **stress**
  - **Any stimulus that creates an imbalance in the internal environment**
  - **Any environmental factor potentially unfavourable to living organisms**

❖Source
- ❖External: **heat, cold, noise** or lack of oxygen
- ❖Internal: **high blood pressure, tumor, pain,** unpleasant thoughts

❖Most stressors are mild and routine however, over-exposure, severe infections and surgical operations are examples of severe stress

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Maintaining Homeostasis

- It is achieved through regulatory mechanisms, eg;
  - regulating level of glucose in the blood
  - regulation of body temperature
- In nearly all animals, three components interact to maintain homeostasis
  - Sensory receptors
  - Integrators and
  - Effectors
- **Sensory receptor**:- these are cells or cell parts that detect stimuli (specific forms of energy)

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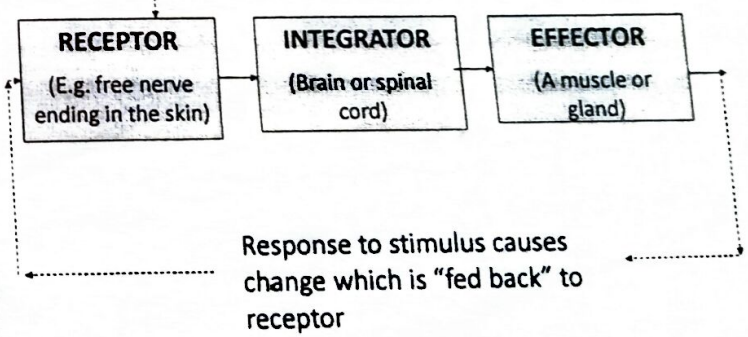
- These receptors are classified based on the types of stimulus they can detect;
  - Thermoreceptors-sensitive to heat or cold
  - Mechanoreceptors-detect changes in pressure, position
  - Pain receptors-detect injury

- Chemoreceptors-detect chemical energy of substances dissolved in the fluids that bathes them
- Osmorecptors-detect changes in the solute levels of body fluid
- Photoreceptors-respond to the energy of visible and ultra violet light

- **Integrator:-** a central command post that polls together information about stimuli and issues signals to the muscles, glands or both. e.g. brain or spinal cord
- **Effector:-** in reaction to signals from the integrators, bring about suitable response(s) e.g. Muscles and glands

Three components of feedback system (loop)

Stimulus (input into system)



APPLICATION OF THE CONTROL SYSTEM

- Every structure from the level of the cell to the system contributes in some way to keep the internal environment within limit
  - Respiratory system
  - Digestive system and related organs
  - Nervous and endocrine system
  - Cardivascular system

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- Homeostasis is maintained by ***feedback mechanisms.***

Definitions:

- A loop system in which the system responds to perturbations either in the same direction (positive feedback) or in the opposite direction (negative feedback).

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- A process in which the level of one substance influences the level of another substance.

- A mechanism or a signal that tends to initiate (or accelerate) or to inhibit (or slow down) a process.

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- **Positive feedback :**

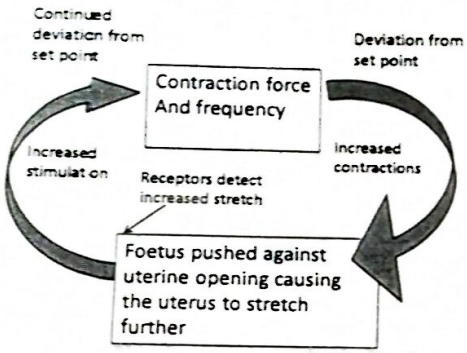
❖ A feedback in which the system responds to the perturbation in the same direction as the perturbation.

❖ feedback mechanism resulting in the amplification or growth of the output signal.

  - In this system, the original perturbation signal is amplified, and the output can grow exponentially or even hyperbolically

  - Positive feedback mechanisms are generally unstable

An example of positive feedback loop is the onset of contractions in childbirth. When contraction begins, the hormone oxytocin is released into the body to stimulate further contractions.



Positive feedback during childbirth

- Another example occurs in blood clotting where clotting factor activates another that cascades quickly leading to the formation of a clot.
- The ripening apple releases the volatile hormone ethylene which accelerates the ripening of unripe fruits in the vicinity
- Breastfeeding

- **Negative feedback:-** A feedback in which the system responds in an opposite direction to the perturbation
  - It is a self-regulatory system in which it feeds back to the input a part of a system's output so as to reverse the direction of change of the output.
  - The process reduces the output of a system in order to stabilize or re-establish internal equilibrium.

- An example is the regulation of blood glucose levels.
- Temperature regulation
- Homeostasis of blood pressure
- Most biologic processes use negative feedback to maintain homeostasis

Regulating levels of glucose in the blood

- Whiles eating, digestion introduces large amount of glucose into the body within a short time
- When the evel within the blood exceeds normal, the excess is transported to the liver and stored as glycogen

- In between meals/while fasting, when glucose level drops below normal range, the liver breaks down its glycogen to add more glucose to the blood stream.
- Thus the glucose level in the blood plasma do not remain elevated immediately after a meal and does not drop too low between meals.

Regulating Body Temperature

- When the temperature of the blood exceeds 37°C, neurons in the hypothalamus detect the change
- Acting through the control of motor neurons, the hypothalamus responds
  - by promoting the dissipation of heat through sweating, dilation of blood vessels in the skin among others

- These responses tends to counter the rise in body temperature
- When body temperature falls, the hypothalamus coordinates different set of responses
  - such as shivering, and constriction of blood vessels in the skin which help to raise the temperature and correct the initial challenge.

- **TEMPERATURE HOMEOSTASIS**
- Thermal Equilibrium is when metabolic heat (Qm) is equal to heat loss (Qe +Qs)
- Qe= Evaporative heat loss
- Qs= Heat loss from
- Conduction
- Convection
- Radiation

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a) Ectotherm = depend on external sources for maintenance of body temperature

b) Endotherm = generate sufficient heat through metabolic processes to regulate body temperature

c) Poikilotherm = body temperature fluctuates with the surrounding environmental temperature

a) Homeotherm = maintains a constant body temperature

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- Usually, ectotherms are poikilothermic and endotherms are homeothermic, but many exceptions exist.

– Many ectotherms maintain relatively constant body temperature by behavioral adjustments and some can increase body temperature through muscular activity

Internal body temperature change has a striking effect on many physiological processes. For many processes, a 10°C increase in temperature will increase the rate of a process by 2 to 3-times.

– Q_{10} = **the change in the rate of a process caused by a 10°C change in body temperature** (defined broadly = temperature effects on a process)

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WATER HOMEOSTASIS/BALANCE

- Much of this is related to temp.
- Highly efficient kidneys
- Metabolic water
- Terrestrial animals and saltwater fish face water conservation problems.
- Saltwater invertebrates (and hagfish) don't, because they are compensators.
- Freshwater animals face problems with ridding themselves of excess water (unless they adopt a compensator strategy).

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Advantages of Homeostasis

- Homeostasis has a survival value because the organism can adjust to changes, for example in temperature and water availability, without it, component cells will be adversely affected since they are having all their needs met by the controlled internal environment.

- Warm blooded animals are capable of living in a range of different habitats from cold polar regions to hot tropical regions because of the effectiveness of their mechanisms for temperature control.

- A constant internal environment makes it possible for cells to become more specialised and efficient in a particular task.

- Thus some cells can become organised into tissues specialised to maintain the ionic composition of the internal environment (e.g.: the kidneys), and others maintain optimum levels of O_2 and CO_2 (e.g.: the lungs).

- The body will attempt to maintain a norm, the desired level of a factor to achieve homeostasis.

- However, it can only work within tolerable limits, where extreme conditions can disable the negative feedback mechanism.

- In these instances, death can result, unless medical treatment is executed to bring about the natural occurrence of these feedback mechanisms

ENVS 454 ENVIRONMENTAL PHYSIOLOGY-Lecture 2

- Extreme environments……..
  - Desert region
  - Cold region
  - High altitude
  - Aquatic environment

Survival Biology

- Survival limits
  - Time at ΔT, ΔP, ΔG
  - Cold, heat, high
- Efforts to adapt
  - Tolerance, adaptation, and resilience
  - Requirements
    - Water and energy
- Vulnerable populations
  - Very young
  - Very sick
  - Very old

- Homeostasis
  - Stability of inner medium is actively regulated
- Stress and strain
  - An external force—stressor or adaptogent—sufficiently intense to exceed a threshold and invoke a biological response produces strain.
- Tolerance
  - Adaptation to a stimulus of constant intensity allows the intensity of the response to decrease over time. Also called habituation.
- Fatigue
  - A diminishing strength of response under the repeated or prolonged influence of a constant stimulus

ADAPTATION

- **Definition:** Refers to some characteristic of an organism (structural, physiological, behavioral, etc.) that increases the fitness of the organism possessing it (i.e., increases its likelihood of survival and reproduction)
- **The adjustment or changes in structure, physiology and behavior of an organism to become more suited to an environment.**
- Adaptations enable living organisms to cope with environmental stresses and pressures.
- These can be structural, behavioral or physiological.

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- ***Structural adaptations*** are special body parts of an organism that help it to survive in its natural habitat (e.g., wing, skin colour, shape, body covering).
- ***Behavioural adaptations*** are special ways a particular organism behaves to survive in its natural habitat (e.g., phototropism).

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- ***Physiological adaptations*** are systems present in an organism that allow it to perform certain biochemical reactions (e.g., making venom, secreting slime, homeostasis).

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- Physiological adaptations covers a huge subject
- Re-emphasizes the constraints imposed by physical environment.
- Every specialization comes with costs.
- Adaptations can be observed at many levels of organization--e.g., biochemistry, cell and tissue anatomy, whole-organism anatomy and behavior
- Most organisms have many, diverse adaptations to physical environment

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- Changes in temperature tolerance with climate changes are called **Acclimatization**

- **Acclimation** is the response to experimental conditions distinguishing adaptations or adjustments in lab experiments from those of acclimatization

The basis for adaptation over the *long term* for *populations* is **genetic variability**.

- Natural selection acts on this genetic variability to preserve favorable traits that increase organismal fitness (these traits are termed adaptive traits)
- Thus, adaptation is a basic process in evolution → changing environments or circumstances result in long-term, or *evolutionary*, alteration of organismal characteristics (including physiology) to meet new demands.
- In this type of adaptive change, the genotype of the organism is modified over time to meet the demands of expected conditions (e.g., organisms native to high altitude show characteristics that are favorable in high altitude situations)

How to detect adaptation?

- **Correlation between a character and an environmental gradient or a functional response**
  - ??? Correlations do not tell you about actual cause-effect relationships
  - Traits can be linked so that the trait you are measuring actually follows variation in another trait on which selection is acting
  - Correlations also don't tell you which trait is driving the correlation
- **Comparisons of individual differences in a character within a species along an environmental gradient.**
  - Also provides only correlative evidence, so no cause-effect relationship can be established
- **Experimental alteration of a character, followed by observation of the impacts of that alteration on organismal function** (e.g., experimental modification of a phenotypic character, gene knockout experiments).
  - Provides better cause-effect information, but often doesn't measure actual fitness effects of the change

- The difficulty with most studies of "adaptation" is that
- actual measurements of the effect of the trait of interest on *fitness* are not usually undertaken.
  - To do that requires following populations over time and noting changes in allele frequencies that occur in response to the experimental treatment.

Adaptation is usually thought of as a change in response to a long-term change in the environment that an organism faces.

How do animals respond to changing environments?

I. Compensators vs. Regulators

a. **Compensators**: allow internal environment to change along with the external environment, yet are able to compensate for these changes and *function in spite of them*. Compensators generally show a *wide range of internal conditions* that allow survival. However, *function may not be optimal over the entire range that is tolerated.*

b. **Regulators**: maintain the internal environment within a narrow range of conditions, even in the face of changing external conditions. Regulators generally show (or tolerate) only a *narrow range of internal conditions* over which function is possible. *Function is optimal, or near optimal, over this narrow range.*

Tolerance and Resistance

- **Tolerance**: the amount of change in the internal environment (brought about by changes in the external environment) that an organism can withstand.
- **Resistance**: after tolerance levels are exceeded, an animal can resist changes in the internal environment for a certain period, depending on how greatly the tolerance levels are exceeded, but will eventually succumb → death.

Phenotypic Plasticity and Phenotypic Flexibility

- **Phenotypic Plasticity**: environmental conditions during development fix a particular phenotype from a given genotype. Different environmental conditions during development can fix a different phenotype from the same genotype.
- **Phenotypic Flexibility**: physiological adjustments within individuals (usually adults) in response to variation in environmental conditions.

Acclimatization

Acclimation

TEMPERATURE REGULATION

TEMINOLOGIES

- ***Homeotherms*** *(*warm blooded)
  - maintain their body temperature above that of the environment - Birds and mammals
- ***Poikilotherm*** *(*cold-blooded)
  - temperature of animal fluctuates with that of its surroundings.

TEMPERATURE REGULATION cont'd...

- ***Heterotherms-***
  - animals that occasionally have high and well regulated body temperatures but at other times are more like cold-blooded animals - deep sea fishes eg. cookiecutter shark, bristlemouths, anglerfish, and viperfish.

TEMPERATURE REGULATION cont'd...

- ***Ectothermy***
  - do not produce heat through physiological means.
  - Body temp depends on environment
  - eg. Invertebrates, fishes, amphibian and reptile
  - may maintain their constant body temp at all times.

TEMPERATURE REGULATION cont'd...

- ***Endothermy***
  - can produce enough heat internally to warm themselves
  - eg. Bird and mammal

Effect of temperature change

- Temperature has striking effects on many physiological processes
- Each metabolic reaction generates heat.
  - what will happen if heat accumulates internally?-core temperature will rise
- Van Hoff's law : If body temperature increases by 10°C, chemical reaction will increase 2-3 times

Effect of temperature change cont'd...

- E.g. Rate of oxygen consumption and all rate processes affected by temperature
- The increase in a rate caused by a 10°C rise in temperature is called the Q_{10}
- Significant variation in the internal temperature could have damaging effects on the body's enzymes.

Heat gain and heat losses

- The heat content of any complex animal depends on the balance between heat gains and losses

Change in Body heat	=	Heat Produced	+	Heat Gained	-	Heat Lost

- Heat is gained and lost through exchanges at the skin and other places by different processes

HEAT GAIN AND HEAT LOSSES cont'd...

- Four (4) process drive these exchanges
  - Radiation
  - Conduction
  - Convection and
  - evaporation

HEAT GAIN AND HEAT LOSSES cont'd...

- **Radiation**:- heat is gained after being exposed to radiant energy (sunlight) or to surfaces warmer than the animals body surface temperature.

- **Conduction**:- heat is exchanged between an animal and an object in direct contact in response to a thermal gradient between them. Heat is lost when the object is cooler then the body and heat is gained when the objet is warmer than the body.

HEAT GAIN AND HEAT LOSSES cont'd...

- **Convection**:- movement of air or water next to the body aids conductive heat loss.

- **Evaporation**:- heat is lost as a liquid converts to a gas. Energy for the conversion comes form the heat content of the liquid

HEAT GAIN AND HEAT LOSSES cont'd...

- Evaporation- has cooling effect,-rate depends on humidity and the rate of air movement
- Animals adjust to heat losses or gains by changing their behavior and physiology
- When outside temperatures change, ectotherms use behavioral temperature regulation,-lizards bask on warm rocks (gain heat by conduction)

Responses to stressful temperatures

- Animals differ in the range of temperatures they can tolerate and this may change with time
- Some organisms are more sensitive to extreme temperatures during certain periods of their lives
  - Survival temperatures
  - Temperatures required for entire life cycle

Responses to stressful temperatures cont'd...

- Diurnal variation (sleep and awake)
  - Nocturnal animal has higher body temp at night but the Diurnal animal has a higher temp during day time
- Normal core body temperature : range of changes
- Variation of body temperature depends on environmental temperature

- The hypothalamus has control for maintaining the core temperature of mammals
- Input is always from peripheral thermoreceptors in skin and other places
- Once there is a deviation from the set point, the centers integrate responses made by skeletal muscles, arterioles in the skin and in some cases sweat glands.