Homeostatic mechanism of major functional system

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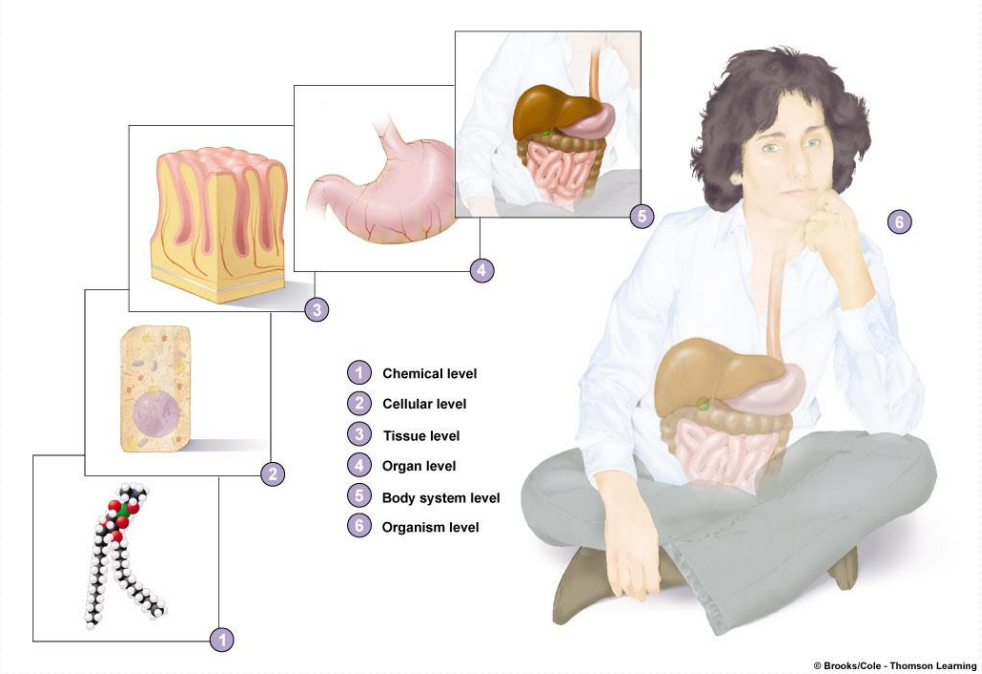
Learning objectives

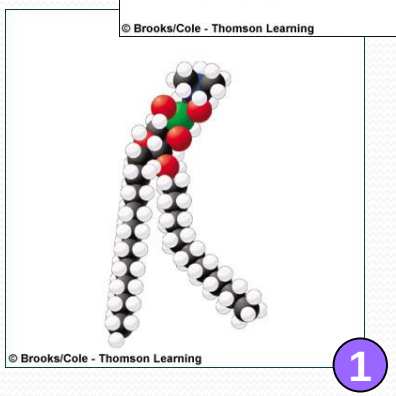
- At the end of lecture ,students should be able to:
- Define homeostasis
- Describe the components of a feedback system
- Contrast the operation of negative & positive feedback systems
- Explain the principles of homeostasis as a central theme of Physiology
- Describe feedforward mechanism with example
- List the factors that contribute to homeostatic imbalance.

Functional Organization of the Body

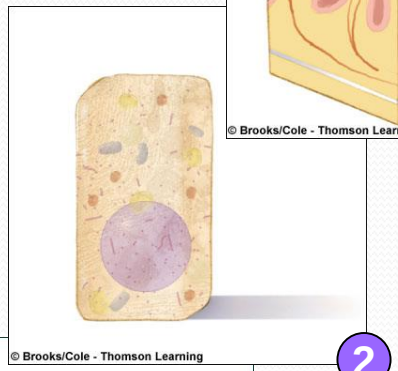
Levels of organization

- Chemical
  - Molecules composed of atoms
- Cellular
  - Cells are basic unit of life
- Tissue
- Organ
- Body system
- Organism

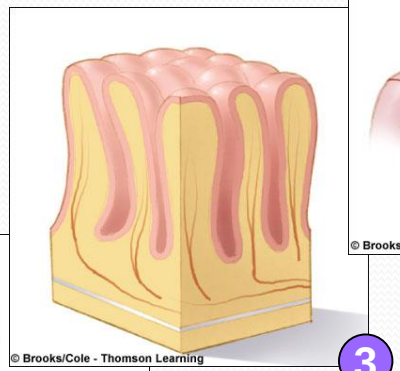




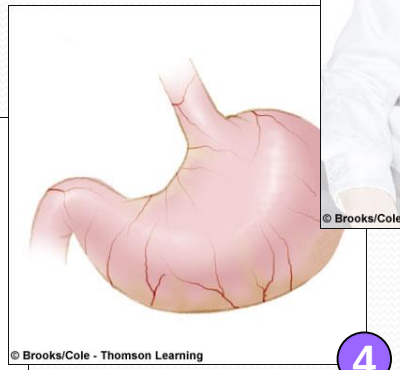
1 Chemical level



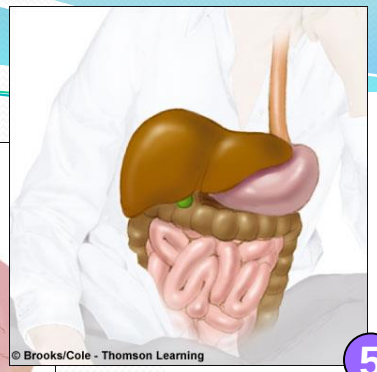
2 Cellular level



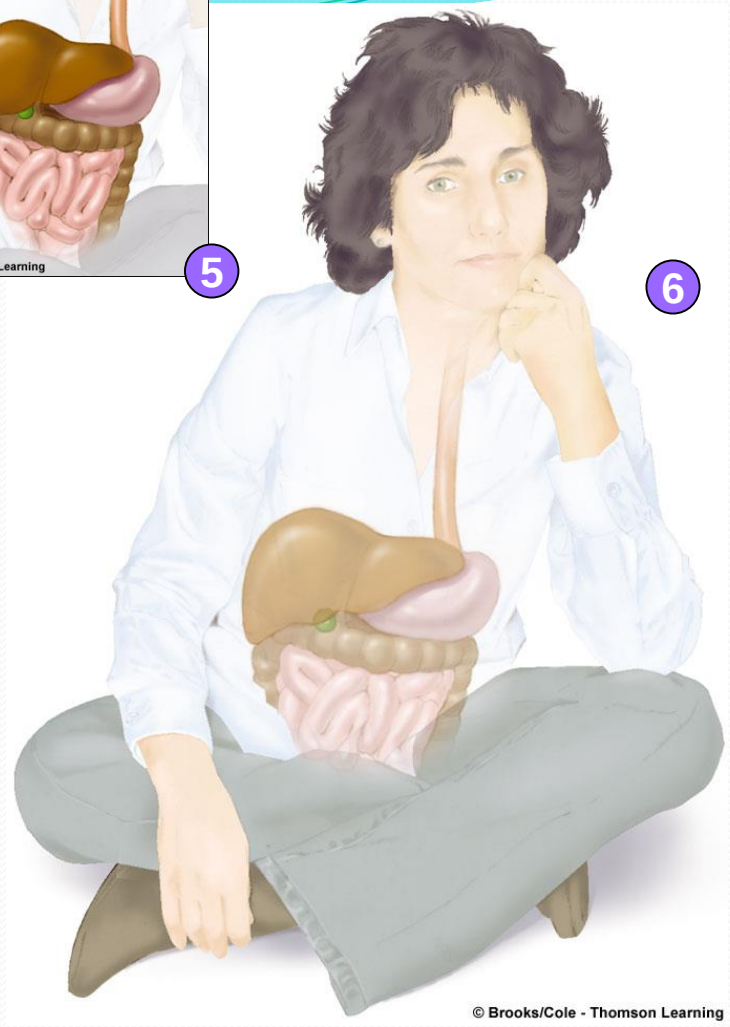
3 Tissue level



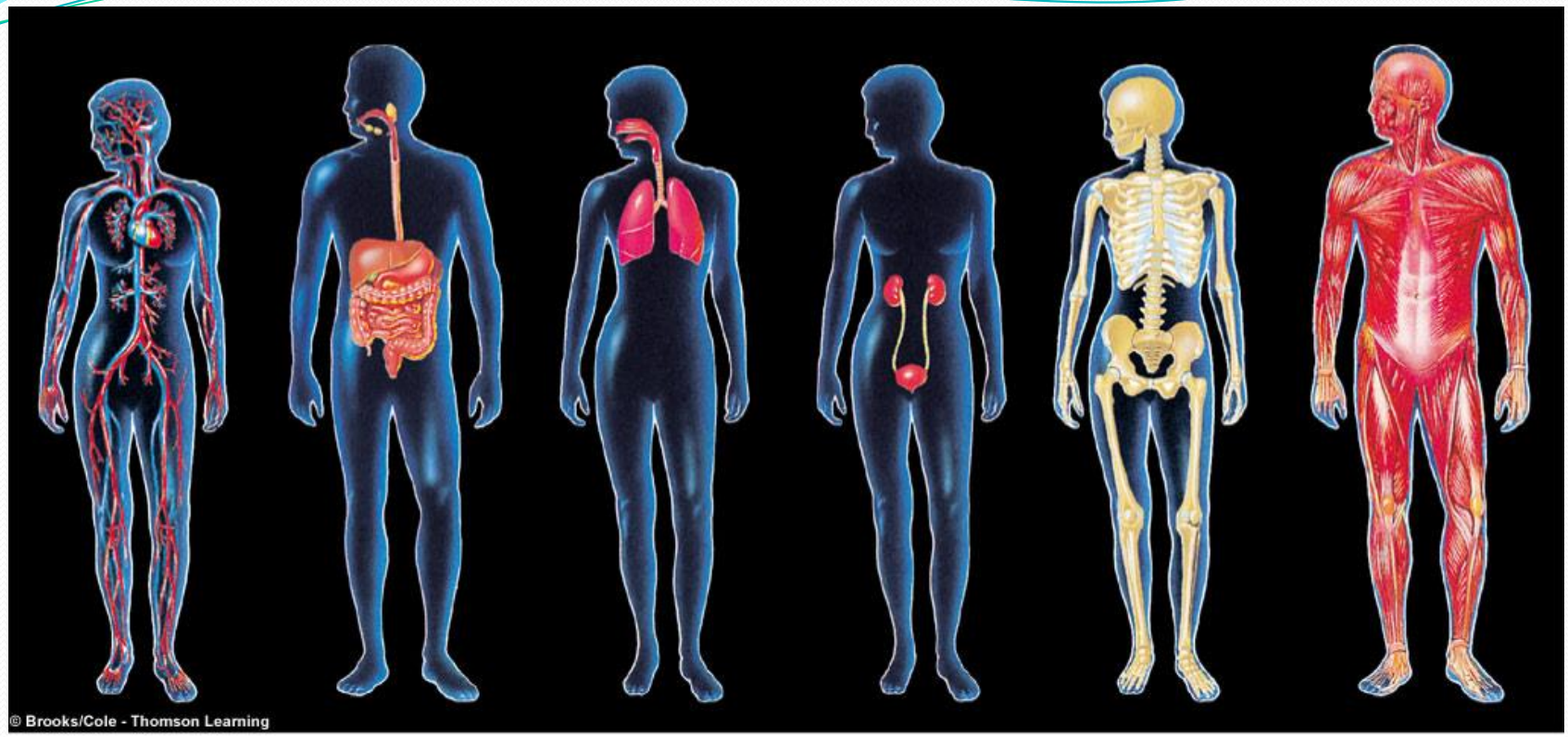
4 Organ level



5 Body system level

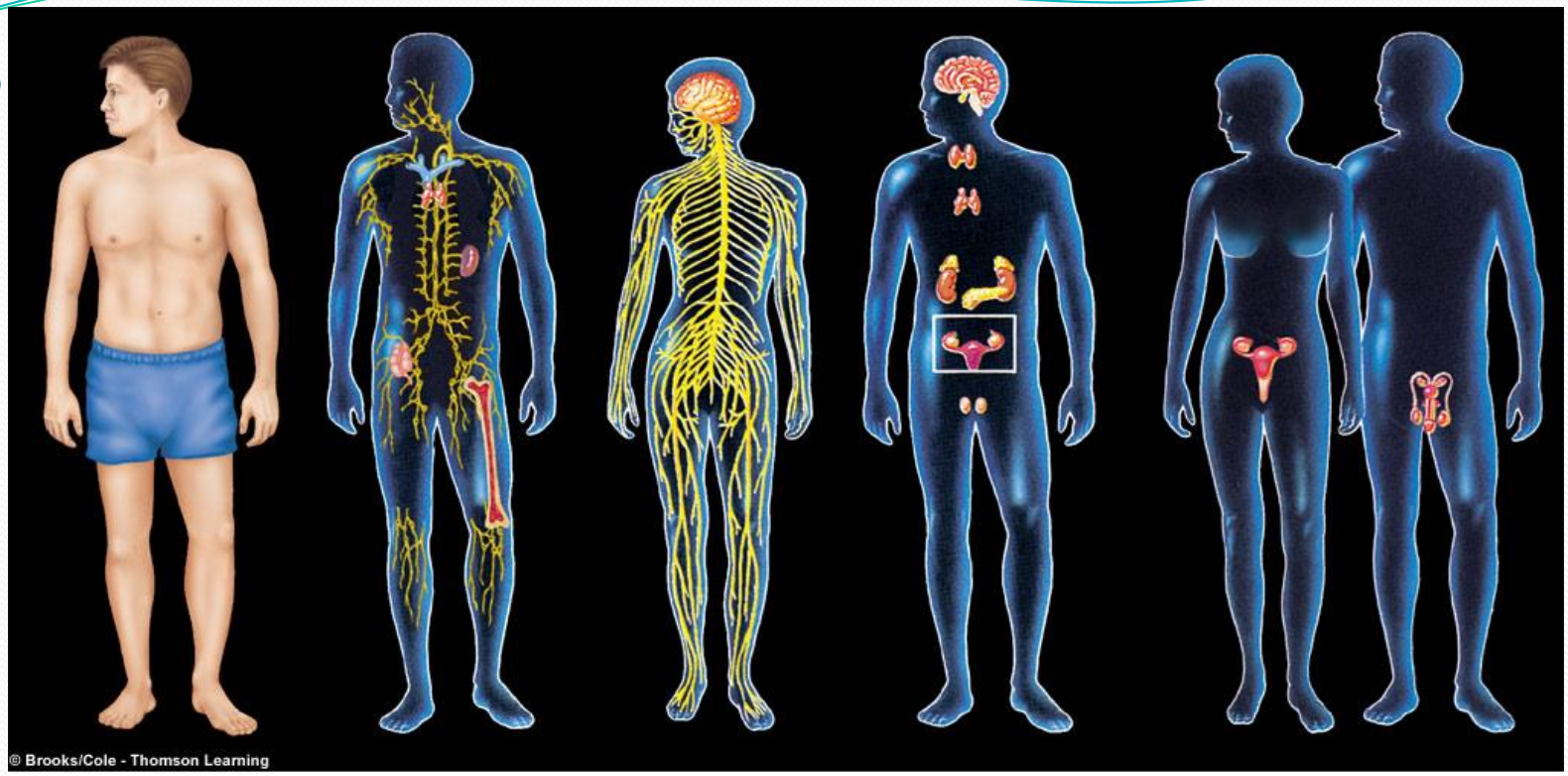


6 Organism level



Circulatory system	Digestive system	Respiratory system	Urinary system	Skeletal system	Muscular system
heart, blood, blood vessels	mouth, pharynx, esophagus, stomach, small intestine, large intestine, salivary glands, exocrine pancreas, liver, gallbladder	Nose, pharynx, larynx, trachea, bronchi, lungs	kidneys, ureters, urinary bladder, urethra	bones, cartilage, joints	skeletal muscles

B



Integumentary system
skin, hair, nails

Immune system
lymph nodes, thymus, bone marrow, tonsils, adenoids, spleen, appendix, and, not shown, white blood cells, gut-associated lymphoid tissue, and skin-associated lymphoid tissue

Nervous system
brain, spinal cord, peripheral nerves, and, not shown, special sense organs

Endocrine system
all hormone-secreting tissues, including hypothalamus, pituitary, thyroid, adrenals, endocrine pancreas, gonads, kidneys, pineal, thymus, and, not shown, parathyroids, intestine, heart, and skin

Reproductive system
Male: testes, penis, prostate gland, seminal vesicles, bulbourethral glands, and associated ducts

Female: ovaries, oviducts, uterus, vagina, breasts

Physiology

"A branch of biology dealing with the functions and activities of living organisms and their parts"

"Physiology is the study of the normal function of cell, tissue, organs, systems and organisms, including all physical and chemical processes."

Physiology (from Ancient Greek: physio = nature; logos = study): study of how the body works to maintain life

- cell □ tissue □ organ □ organ system □ organism

Human physiology is the scientific study of normal body function.

Physiology Study of Functions of Living Things

- Two approaches to explain body functions
- Emphasis on purpose of body process (Why)

Explanations are in terms of meeting a bodily need

- Emphasis on Mechanism (How)

Explanations are in terms of cause and effect sequences

- Body is viewed as a machine.

Homeostasis

The maintenance of a constant environment in the body is called Homeostasis

Homeostasis

- Maintain – keep up.
- Constant – the same.
- Internal – inside the body.
- Environment – surroundings of the body.

Homeostasis

The term ‘Homeostasis’ is derived from two Greek words;

Homeo which means **‘unchanging’**

Stasis which means **‘standing’**

Defined as maintenance of a relatively stable internal environment

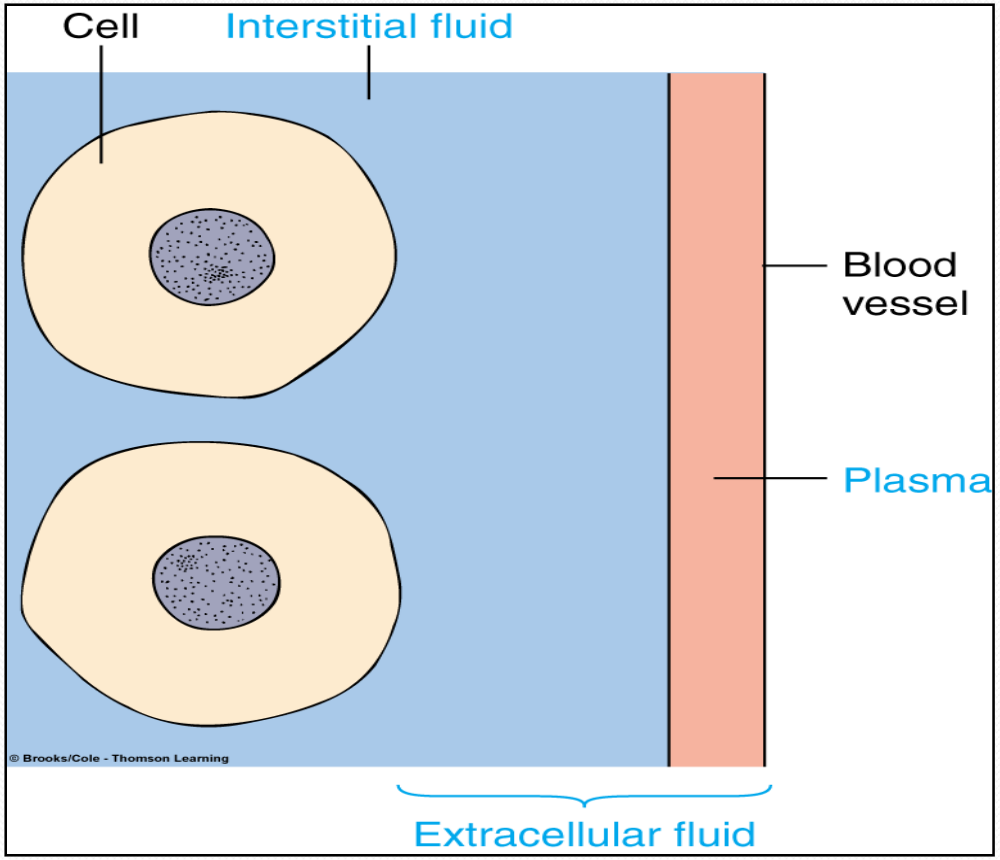
So, a better definition of 'Homeostasis' is **the maintenance of the internal environment within narrow limits**

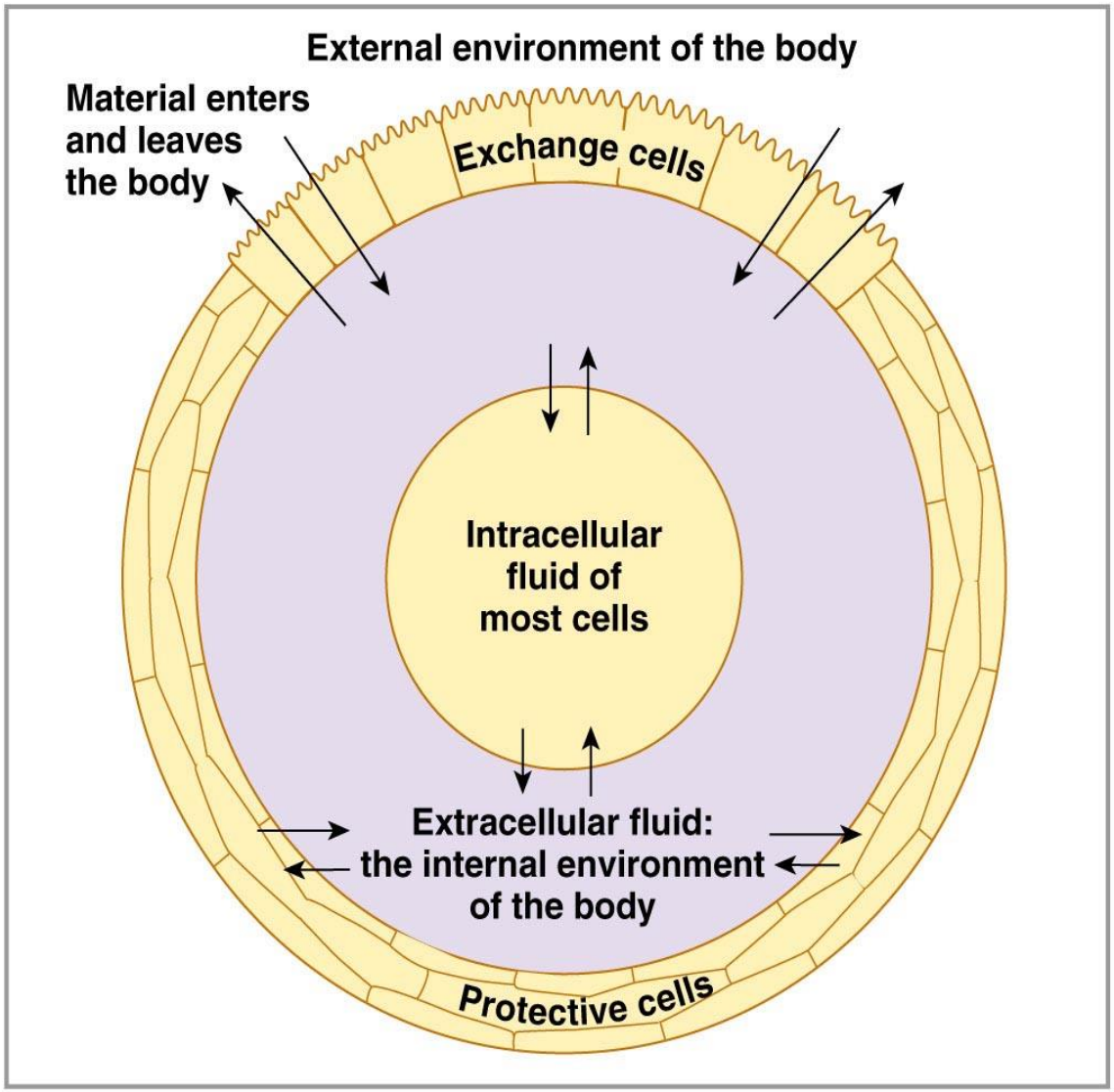
Homeostasis

- Defined as maintenance of a relatively stable internal environment
  - Does not mean that composition, temperature, and other characteristics are absolutely unchanging
- Homeostasis is essential for survival and function of all cells
- Each cell contributes to maintenance of a relatively stable internal environment

Homeostasis

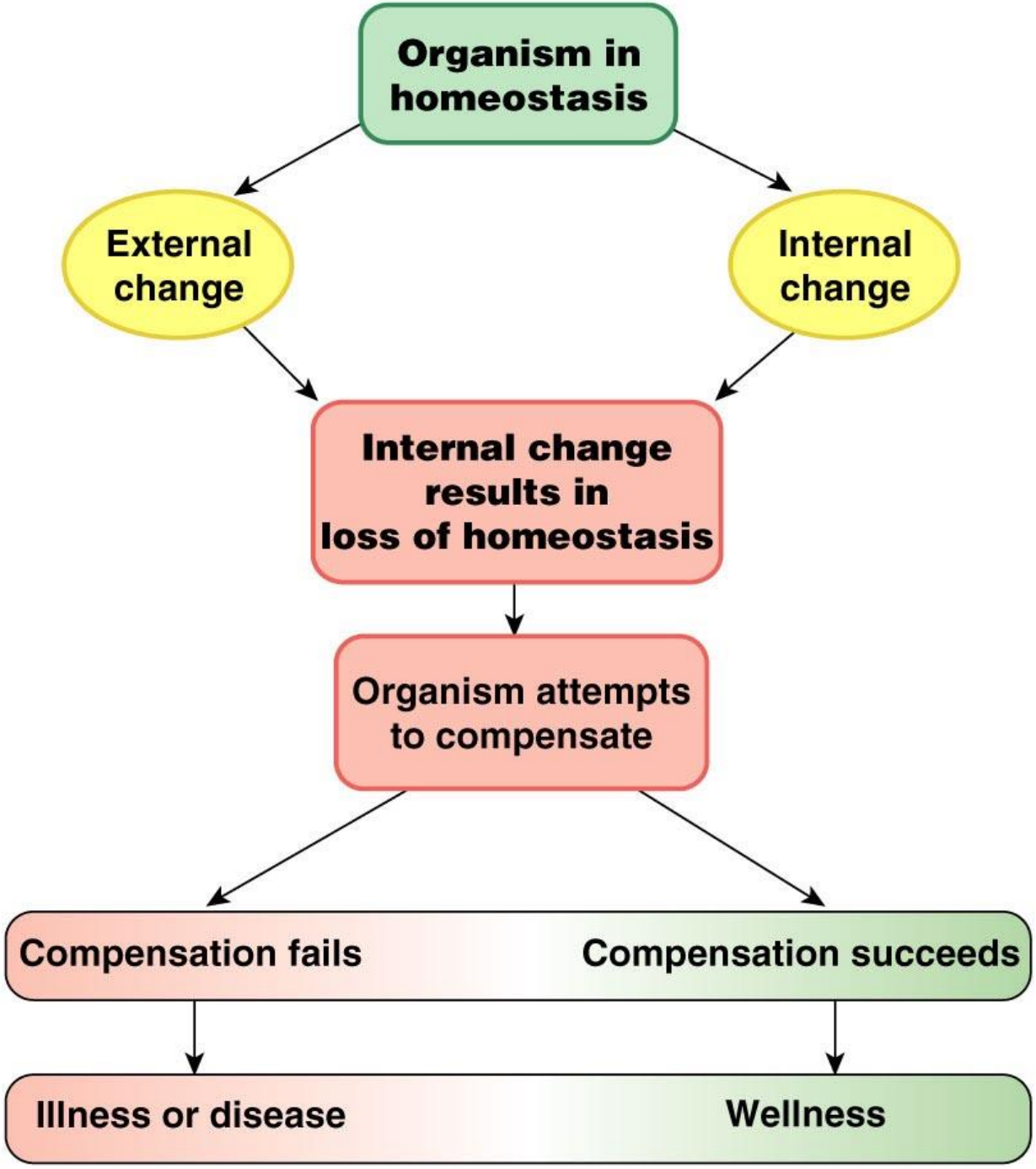
- Body cells are contained in watery internal environment through which life-sustaining exchanges are made
- Extracellular fluid (ECF) - Fluid environment in which the cells live (fluid outside the cells)
  - Two components:
    - Plasma
    - Interstitial fluid
- Intracellular fluid (ICF) - Fluid contained within all body cells




External environment of the body
Material enters and leaves the body
Exchange cells
Intracellular fluid of most cells
Extracellular fluid: the internal environment of the body
Protective cells

- Homeostasis is continually being disrupted by
  - External stimuli:
    - heat, cold, lack of oxygen, pathogens, toxins
  - Internal stimuli:
    - Body temperature
    - Blood pressure
    - Concentration of water, glucose, salts, oxygen, etc.
    - Physical and psychological distresses

Homeostasis



Homeostatic Control Systems

- **Detect deviations from normal** (set point) in the internal environment that need to be held within narrow limits
- **Integrate this information** with other relevant information
- **Make appropriate adjustments** in order to restore factor to its desired value

Homeostasis

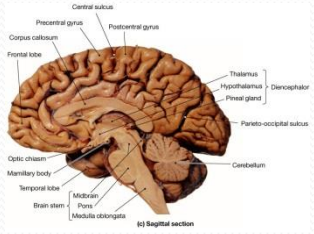
- Homeostasis involves dynamic mechanisms that detect and respond to deviations in physiological variables from their “set point” values by initiating effector responses that restore the variables to the optimal physiological range.
- Two systems that maintain homeostasis are: Nervous system & Endocrine system

Maintenance of Homeostasis

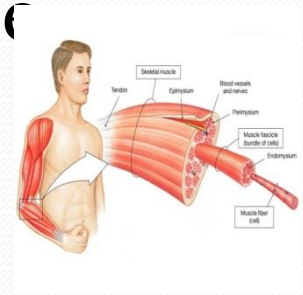
- Nervous system
  - Controls and coordinates bodily activities that require rapid responses
  - Detects and initiates reactions to changes in external environment
- Endocrine system
  - Secreting glands of endocrine regulate activities that require duration rather than speed
  - Controls concentration of nutrients and, by adjusting kidney function, controls internal environment's volume and electrolyte composition

- Receptor - structures that monitor a controlled condition and detect changes

- Control center - determines next action



- Effector
  - Receives directions from the control center
  - Produces a response that restores the controlled condition



- **Feedforward** - term used for responses made in anticipation of a change

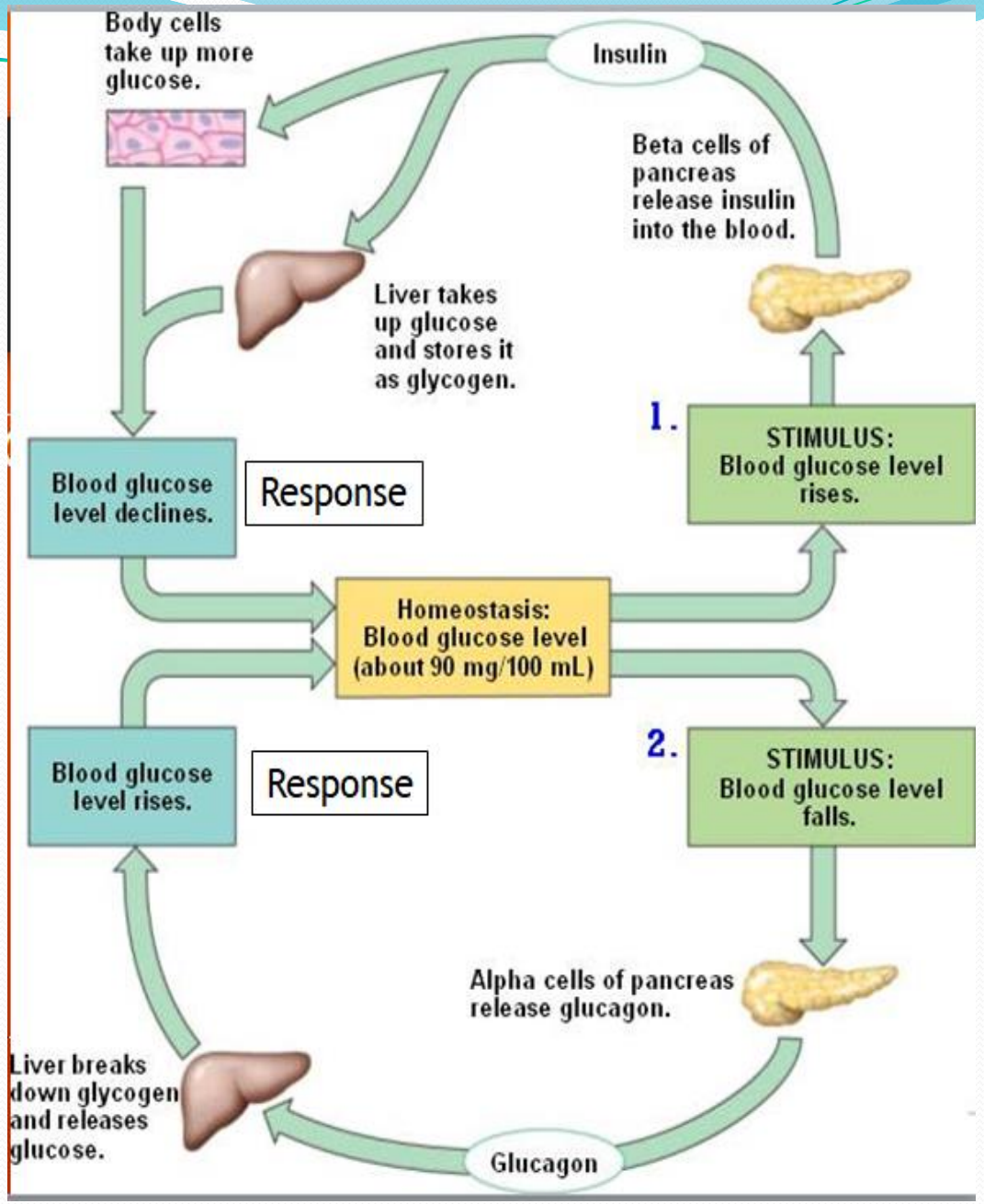
- **Feedback** - refers to responses made after change has been detected
  - **Types of feedback systems**
    - Negative
    - Positive

- **Negative feedback loop**
  - original stimulus reversed
  - most feedback systems in the body are negative
  - used for conditions that need frequent adjustment
- **Positive feedback loop**
  - original stimulus intensified
  - seen during normal childbirth

Negative Feed Back Mechanism

If the response reverses the original stimulus

Eg: GLUCOSE HOMEOSTASIS

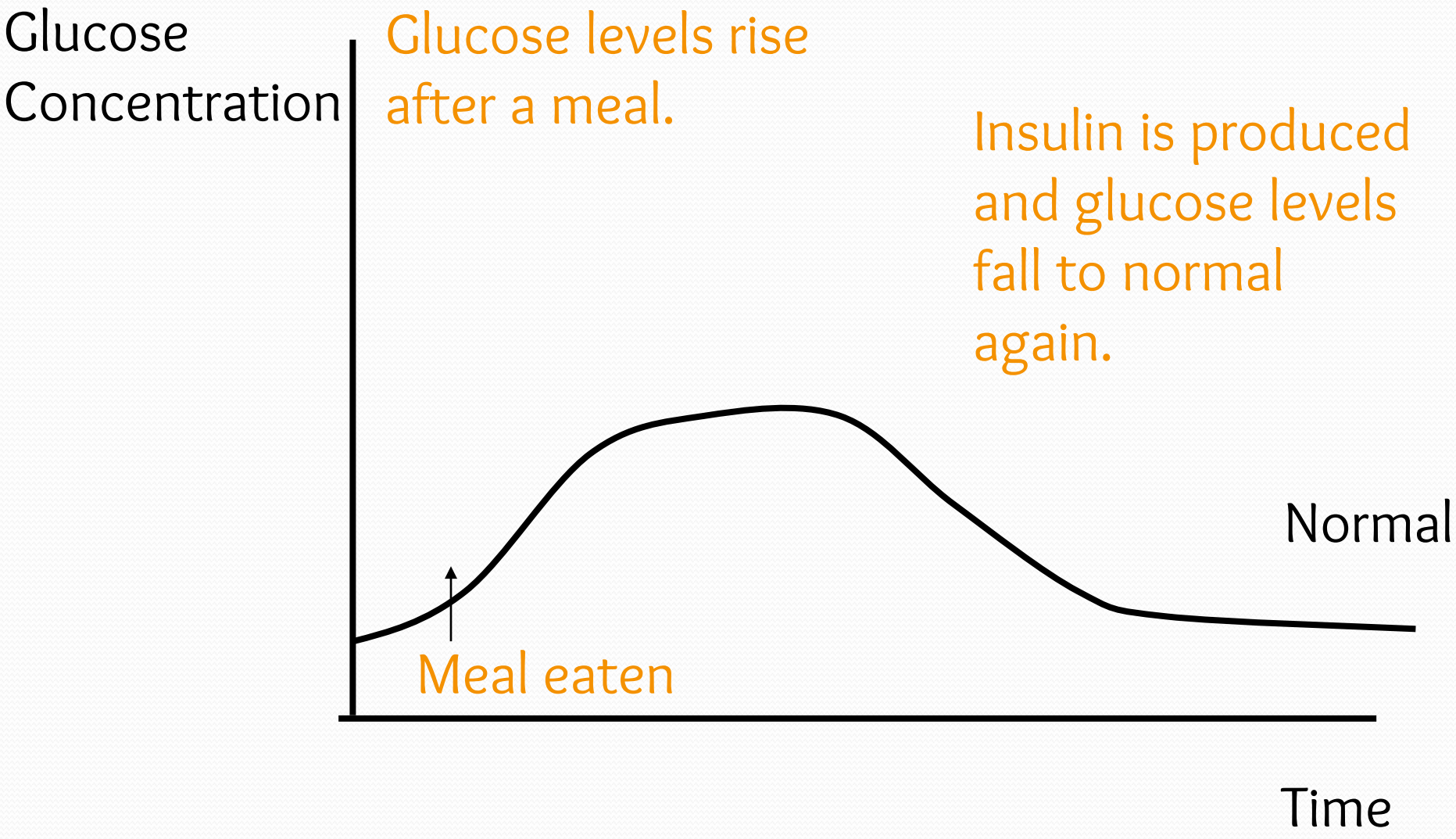


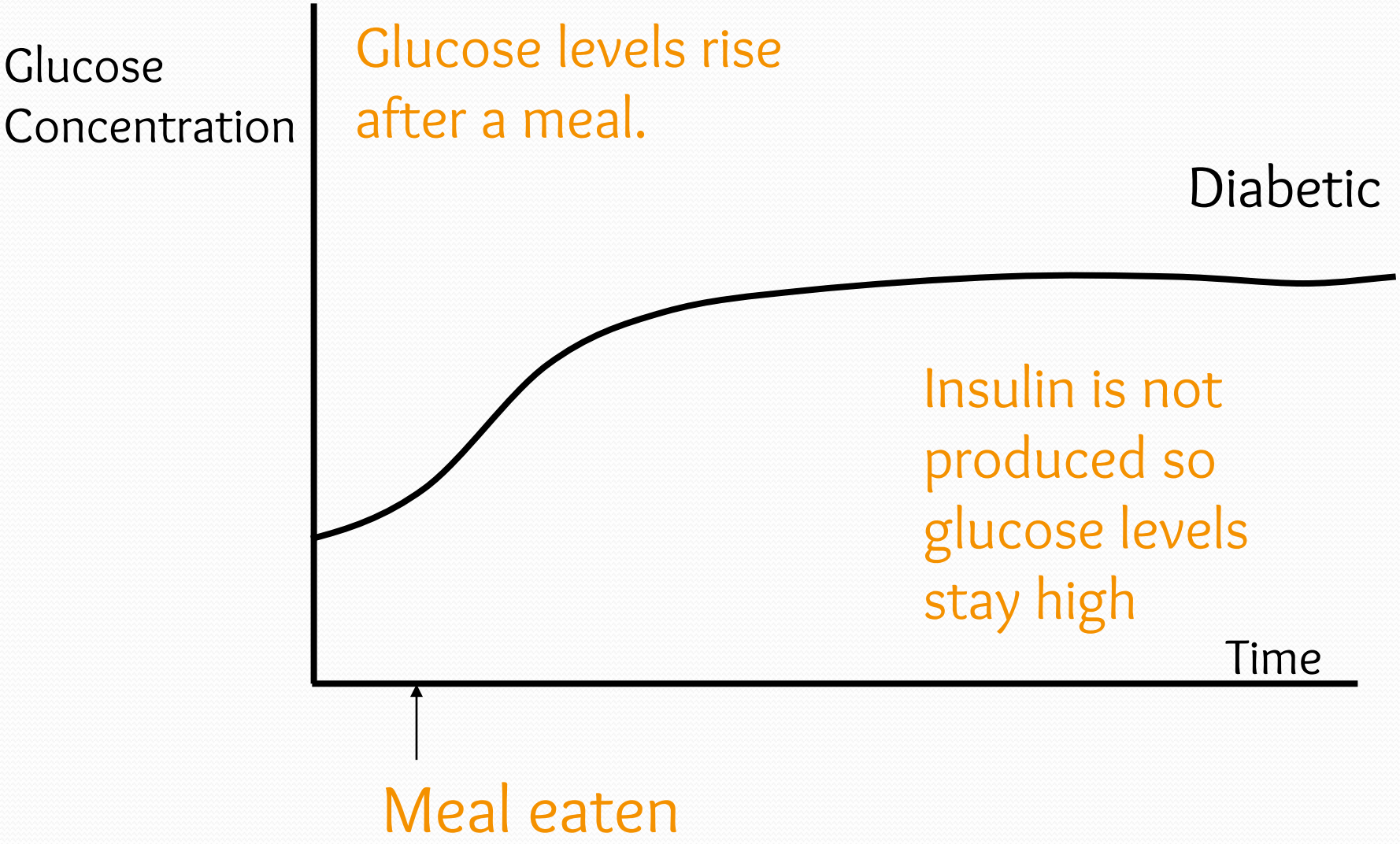
CONTROLLING BLOOD GLUCOSE LEVELS

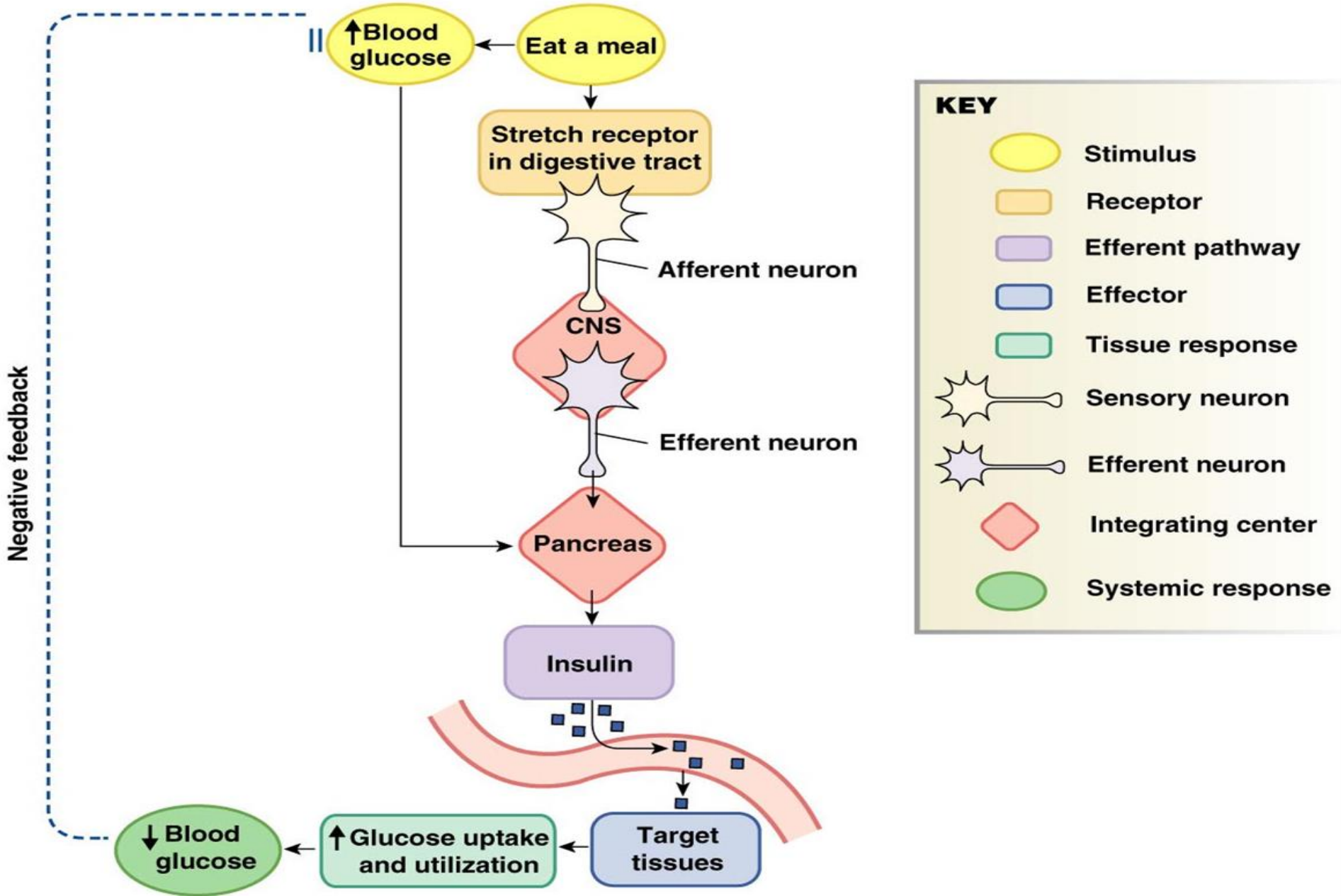
- This is regulated by 2 hormones from the **pancreas** called:

Insulin

Glucagon


Glucose Concentration
Glucose levels rise after a meal.
Insulin is produced and glucose levels fall to normal again.
Normal
Meal eaten
Time

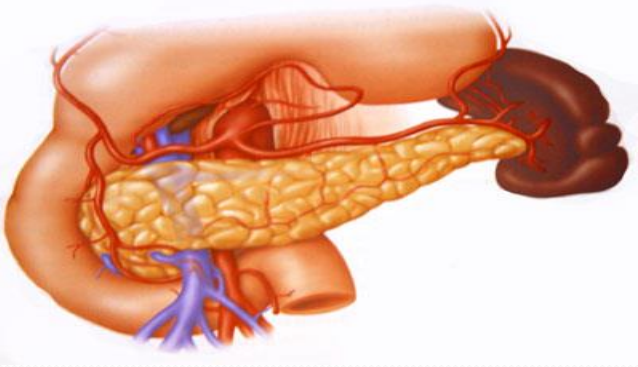

Glucose Concentration
Glucose levels rise after a meal.
Diabetic
Insulin is not produced so glucose levels stay high
Time
Meal eaten


↑Blood glucose
Eat a meal
Stretch receptor in digestive tract
Afferent neuron
CNS
Efferent neuron
Pancreas
Insulin
↓Blood glucose
↑Glucose uptake and utilization
Target tissues
Negative feedback
KEY
Stimulus
Receptor
Efferent pathway
Effector
Tissue response
Sensory neuron
Efferent neuron
Integrating center
Systemic response

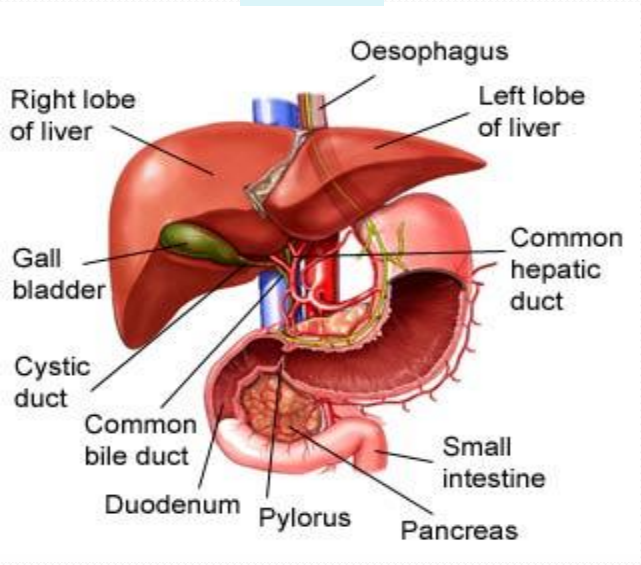
Glucose and Insulin

- Glucose intake occurs during digestion of food that is needed for energy expenditure to perform routine physical activities.
- The pancreas is the key organ that regulates the glucose levels in body by secreting two hormones, insulin and glucagon.
- The liver also helps to store the excess glucose in form of glycogen to be utilized later.

Pancreas



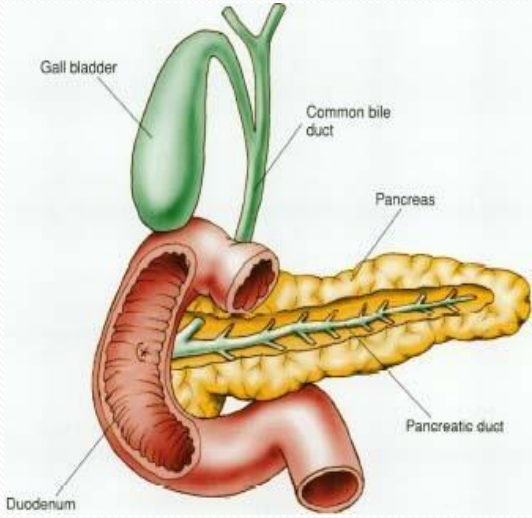
Liver



Glucose and Insulin Negative Feedback Loop

Boy eating cake

Increases Glucose Levels



Stimulates β cells of pancreas to secrete insulin

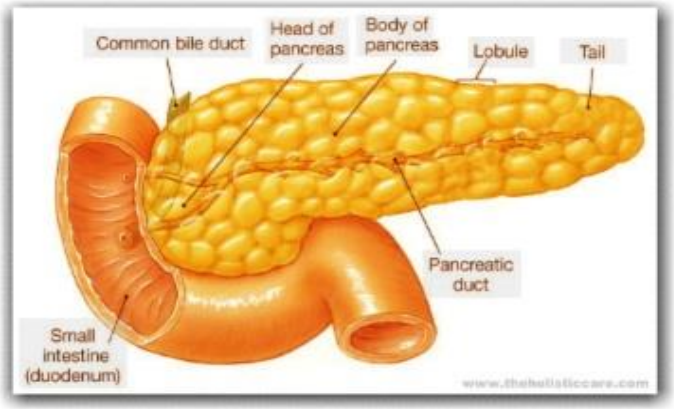
Insulin stimulates the cells to take up glucose from the blood.

Lowers Blood Glucose levels

CYCLE 1

CYCLE 2

Low Blood Glucose Levels



Stimulated Alpha Cells in Pancreas

Glucagon is released

Glucagon stimulates liver cells to release glucose into the blood

High blood glucose levels and Cycle 1 continues

Glucose and Insulin Negative Feedback Loop

- Two primary Hormones

Insulin

↓

Lowers Blood Glucose Levels

Glucagon

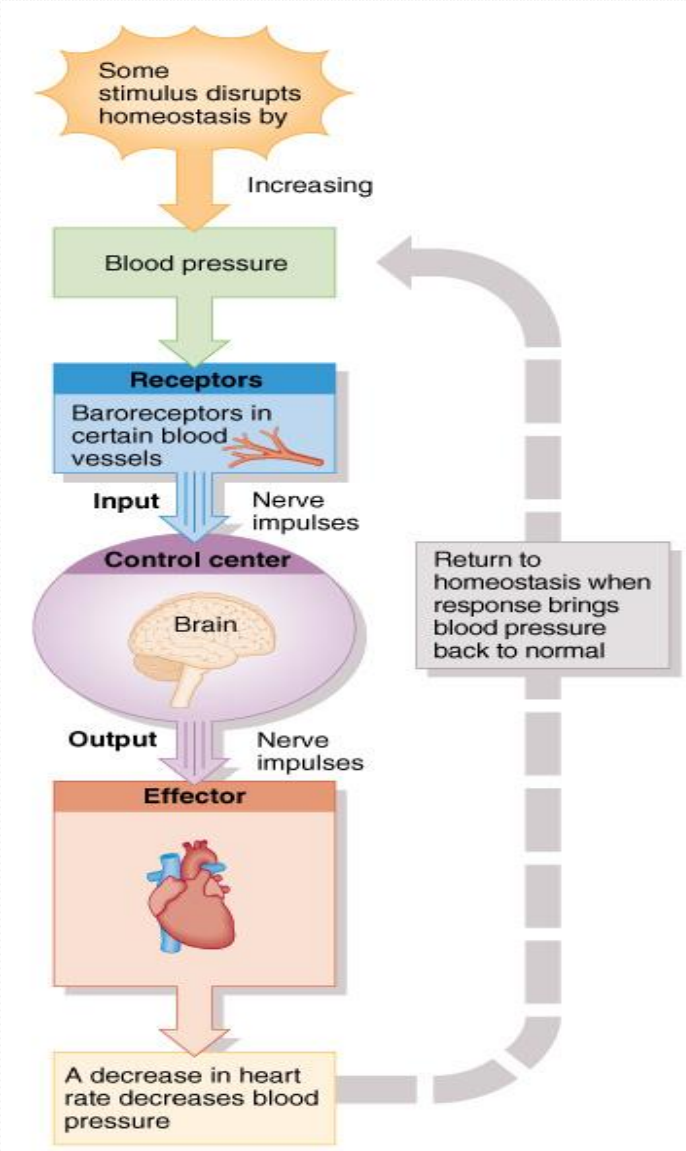
↓

Raises Blood Glucose Levels

The opposite actions of these two hormones, insulin and glucagon, helps to maintain normal blood sugar levels in the body hence maintain homeostasis of the body.

Control of Blood Pressure

- Baroreceptors in walls of blood vessels detect an increase in BP
- Brain receives input and signals blood vessels and heart
- Blood vessels dilate, HR decreases
- BP decreases

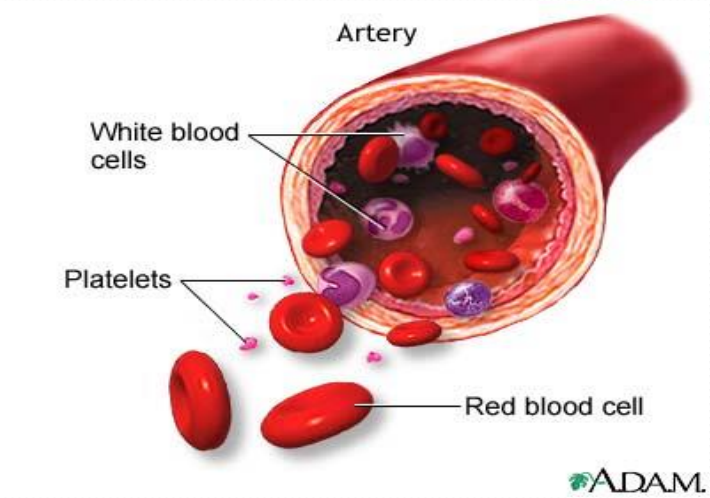


Temperature regulation of Body

- Animals that are capable of maintaining their body temperature within a given range are called homeotherms.
- Temperature is regulated by negative feedback control.
- Thermoreceptors located in hypothalamus detect temperature fluctuations in the body.

Temperature Regulation of the Body

- Increased temperature causes vasodilatation (blood vessels near the surface of the skin dilate).
- The large surface area allows heat to be lost from the blood and lowers the body temperature.



- Sweating also helps lower the temperature.
- Decreased temperature causes vasoconstriction (blood vessels constrict) and minimal heat loss occurs which helps maintain body temperature.
- Hair on the body provides insulation and helps maintain body temperature.

Positive Feedback

- A positive feedback loop occurs when the output of a system acts to enhance the changes to the input of the system.

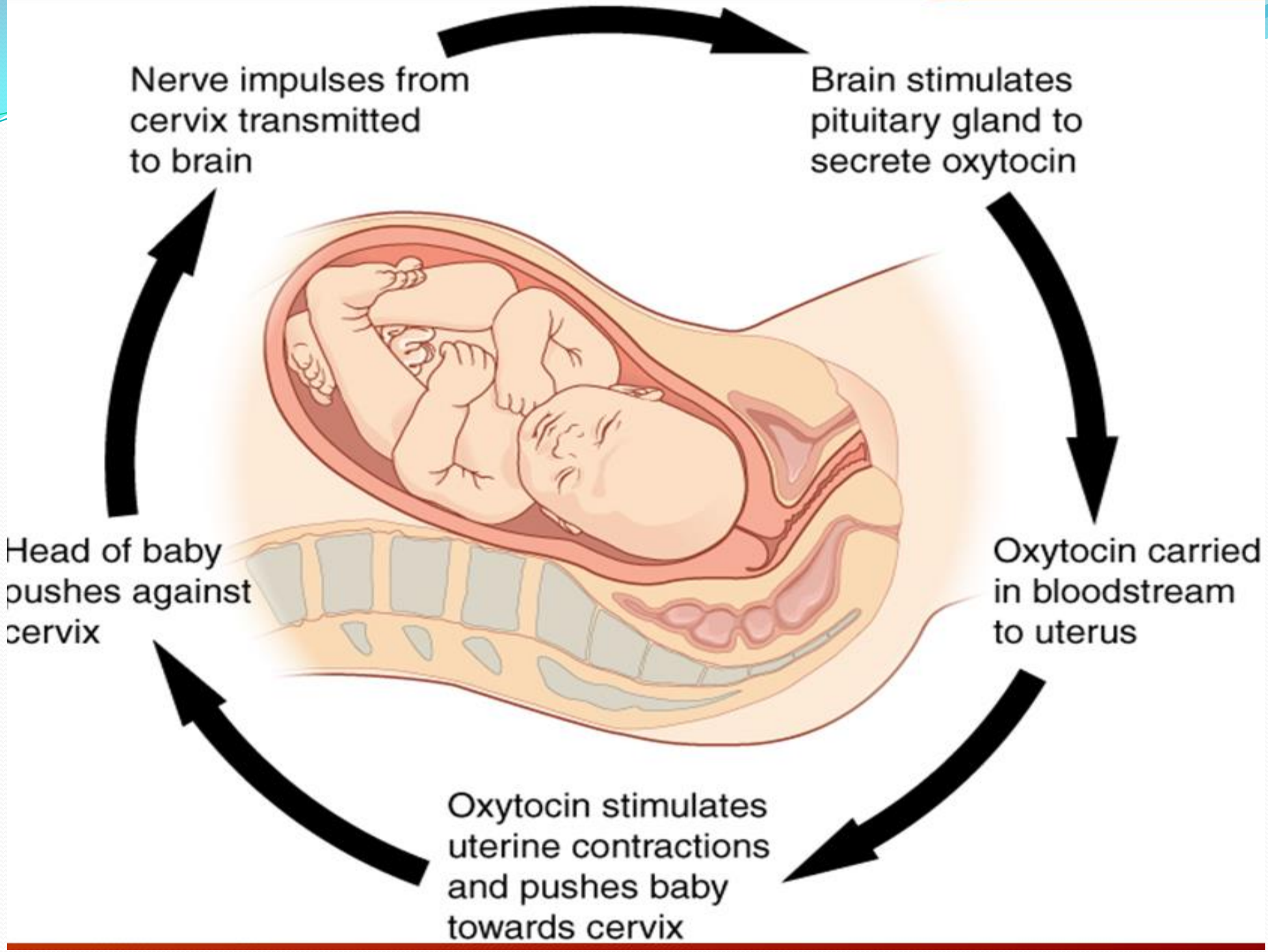
- One example of a biological positive feedback loop is the onset of contractions in childbirth.

  - When a contraction occurs, the hormone oxytocin is released into the body, which stimulates further contractions.

  - This results in contractions increasing in amplitude and frequency.

Positive Feedback

- Stretch receptors in walls of uterus send signals to the brain
- Brain induces release of hormone (oxytocin) into bloodstream
- Uterine smooth muscle contracts more forcefully
- More stretch, more hormone, more contraction etc.
- Cycle ends with birth of the baby & decrease in stretch


Nerve impulses from cervix transmitted to brain
Brain stimulates pituitary gland to secrete oxytocin
Head of baby pushes against cervix
Oxytocin carried in bloodstream to uterus
Oxytocin stimulates uterine contractions and pushes baby towards cervix

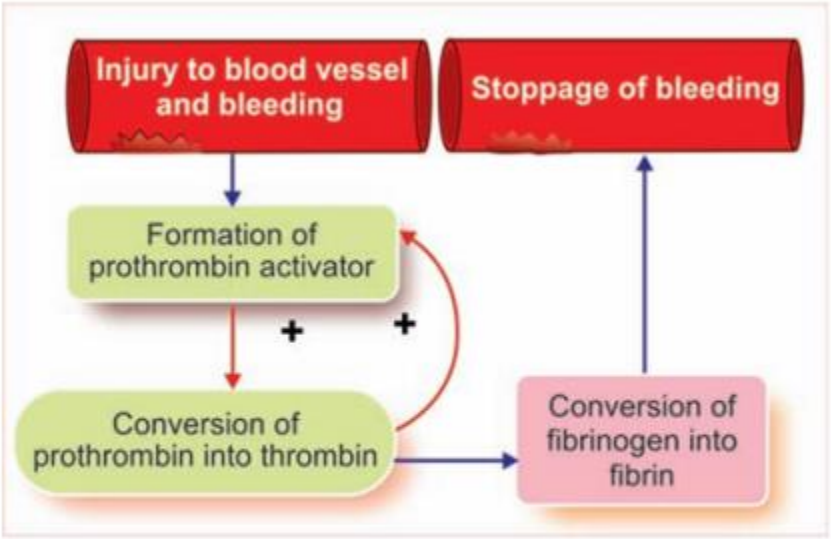


FIGURE 4.4: Positive feedback mechanism – coagulation of blood. Once formed, thrombin induces the formation of more prothrombin activator.

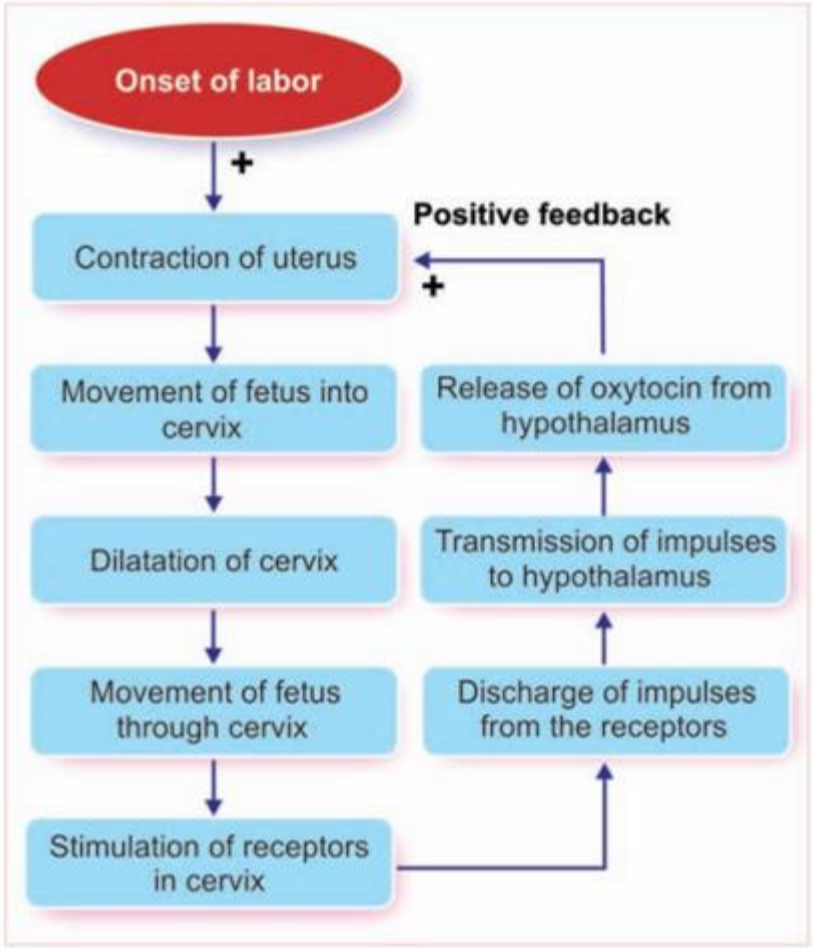


FIGURE 4.5: Positive feedback mechanism – parturition

Positive Feedback

- Another example is blood clotting.
  - The loop is initiated when injured tissue releases signal chemicals that activate platelets in the blood.
  - An activated platelet releases chemicals to activate more platelets, causing a rapid cascade and the formation of a blood clot.

- Lactation involves positive feedback so that the more the baby suckles, the more milk is produced.

Factors homeostatically regulated include

- Concentration of nutrient molecules e.g glucose
- Concentration of water, salt, and other electrolytes
- Concentration of waste products
- Concentration of O_2 = 100mmHg and CO_2 = 40 mmHg
- pH = 7.35
- Blood volume 4-6 L and pressure 120/80
- Temperature = 37° C

Positive Feedback

- In most cases, once the purpose of the feedback loop is completed, counter-signals are released that suppress or break the loop.
  - Childbirth contractions stop when the baby is out of the mother's body.
  - Chemicals break down the blood clot.
  - Lactation stops when the baby no longer nurses.

- Body cells work best if they have the correct
  - Temperature
  - Glucose concentration
  - Water levels

- Human body temperature 37ºC.
  - E.g. If your body is in a hot environment your body temperature is 37ºC
  - If your body is in a cold environment your body temperature is still 37ºC

Control of body temperature

Sweating

- When your body is hot, sweat glands are stimulated to release sweat.
- The liquid sweat turns into a gas (it evaporates)
- To do this, it needs heat.
- It gets that heat from your skin.
- As your skin loses heat, it cools down.

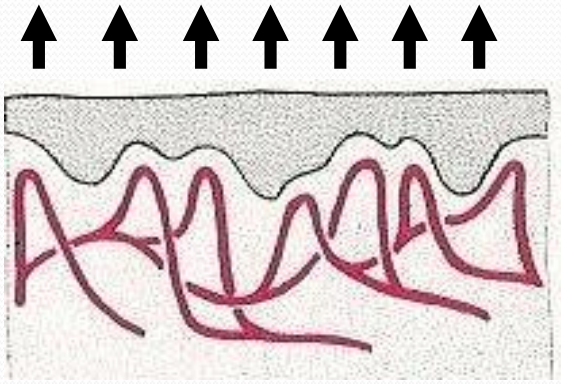
Piloerection

It is sometimes called “goose bumps” or “chicken skin”!

- This is when the hairs on your skin “stand up” .
- The hairs trap a layer of air next to the skin which is then warmed by the body heat
- The air becomes an insulating layer.

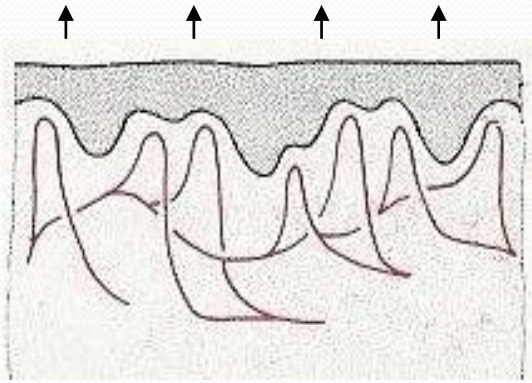
Vasodilation

If the body temperature rises, the blood vessels in the skin dilate (become wider) and allow more blood to flow near the surface. The heat loss from the blood through the skin helps cool the circulating blood

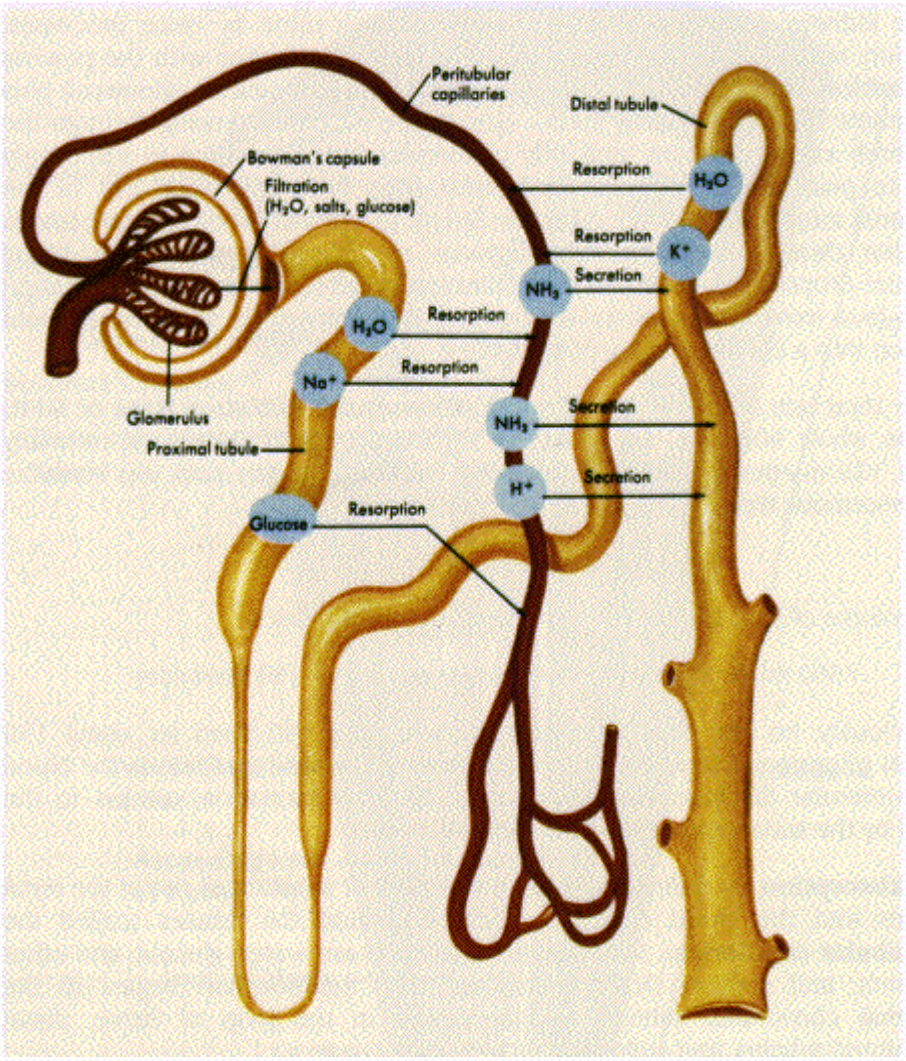


Vasoconstriction

If the body temperature falls. The blood vessels in the skin constrict. Less warm blood flows near the surface so less heat is lost



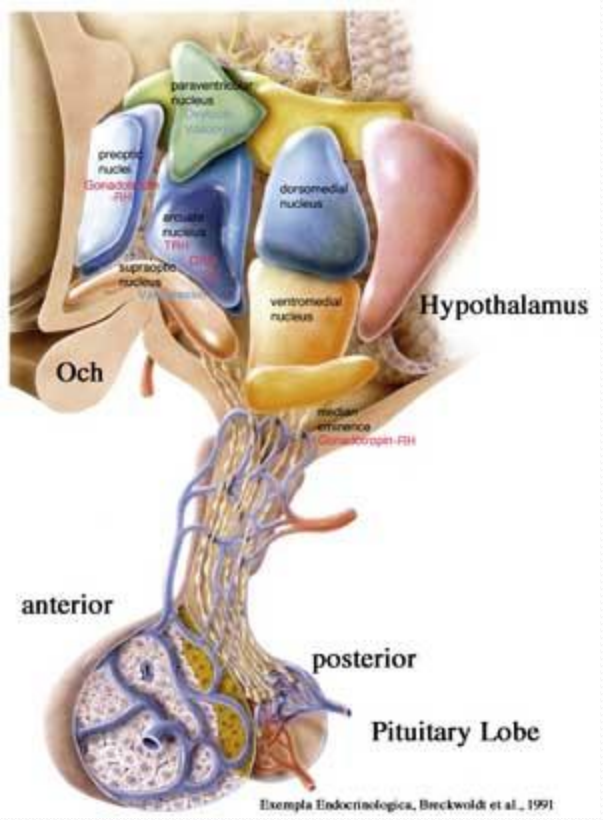
Kidney and Water Regulation



- The nephron is the most important functional part of the kidney.
- It filters nutrients like salts and amino acids in the Bowman's capsule into ascending loop and filters the urine.

Kidney and Water Regulation

Anti-Diuretic Hormone, ADH (also called vasopressin), is secreted by the pituitary gland and acts on the nephron to conserve water and regulate the tonicity of body fluids.



Anti-Diuretic Hormone

ADH acts on Nephron to reabsorb water and decrease blood osmolality (saltiness)

ADH regulated water conservation in kidneys

Less water in the blood

Stimulates osmoreceptors in hypothalamus to send signals to the pituitary gland

Pituitary glands secretes high levels of ADH

ADH makes the tubules more permeable and more water is reabsorbed back into the bloodstream (urine is concentrated).

Excess water in the blood

Stimulates osmoreceptors in hypothalamus to send signals to the pituitary gland

Pituitary glands secretes low levels of ADH

Less ADH makes the tubules less permeable and less water is reabsorbed back into the bloodstream (urine is dilute).

ADH regulated water conservation in kidneys

- Osmoregulators send negative feedback to the hypothalamus about the concentration of water in the bloodstream.
- The hypothalamus then stimulates the pituitary glands to secrete high or low concentrations of anti-diuretic hormone.
- ADH then makes the tubules more or less permeable and hence, maintains water and electrolyte homeostasis.

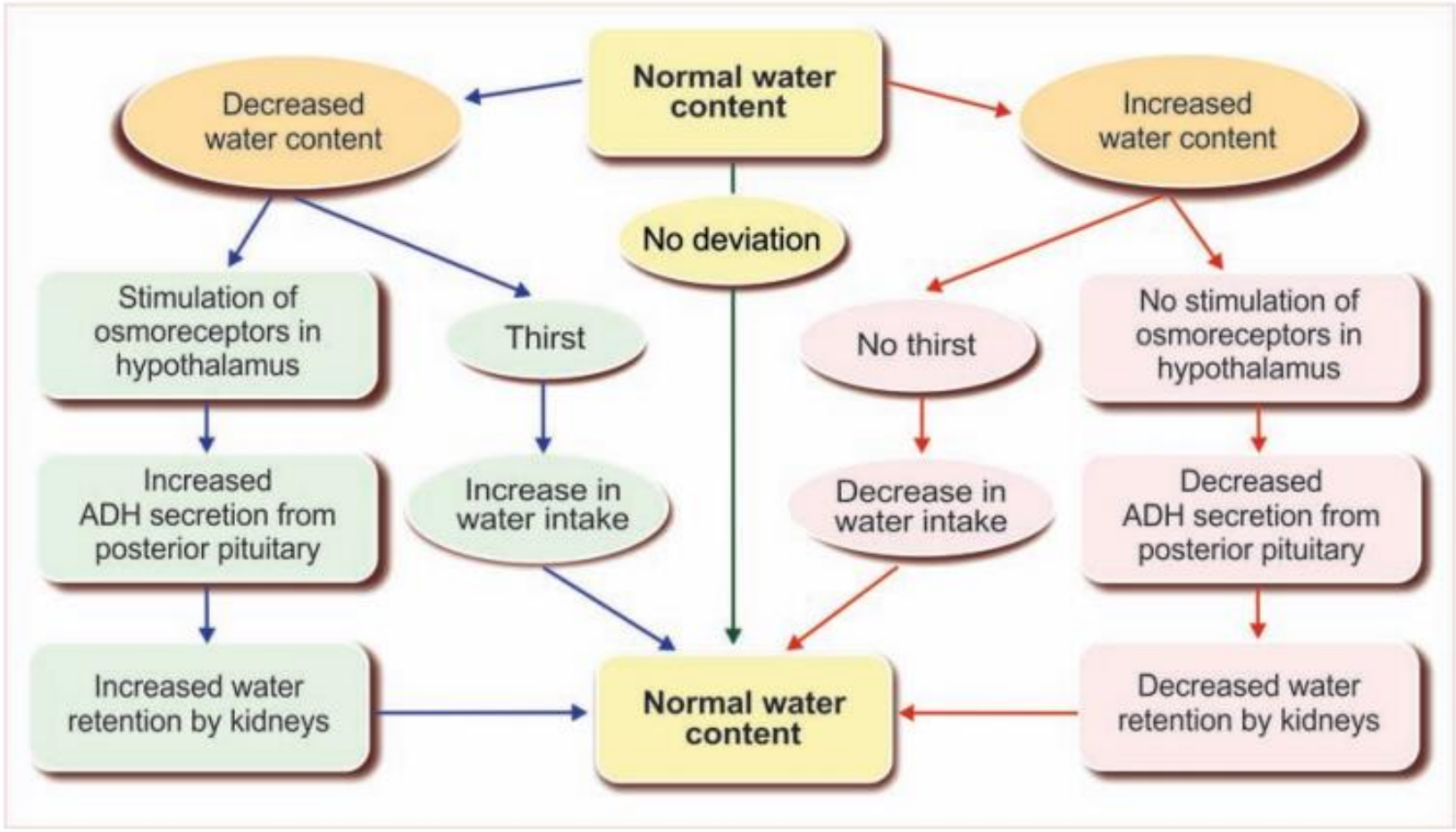
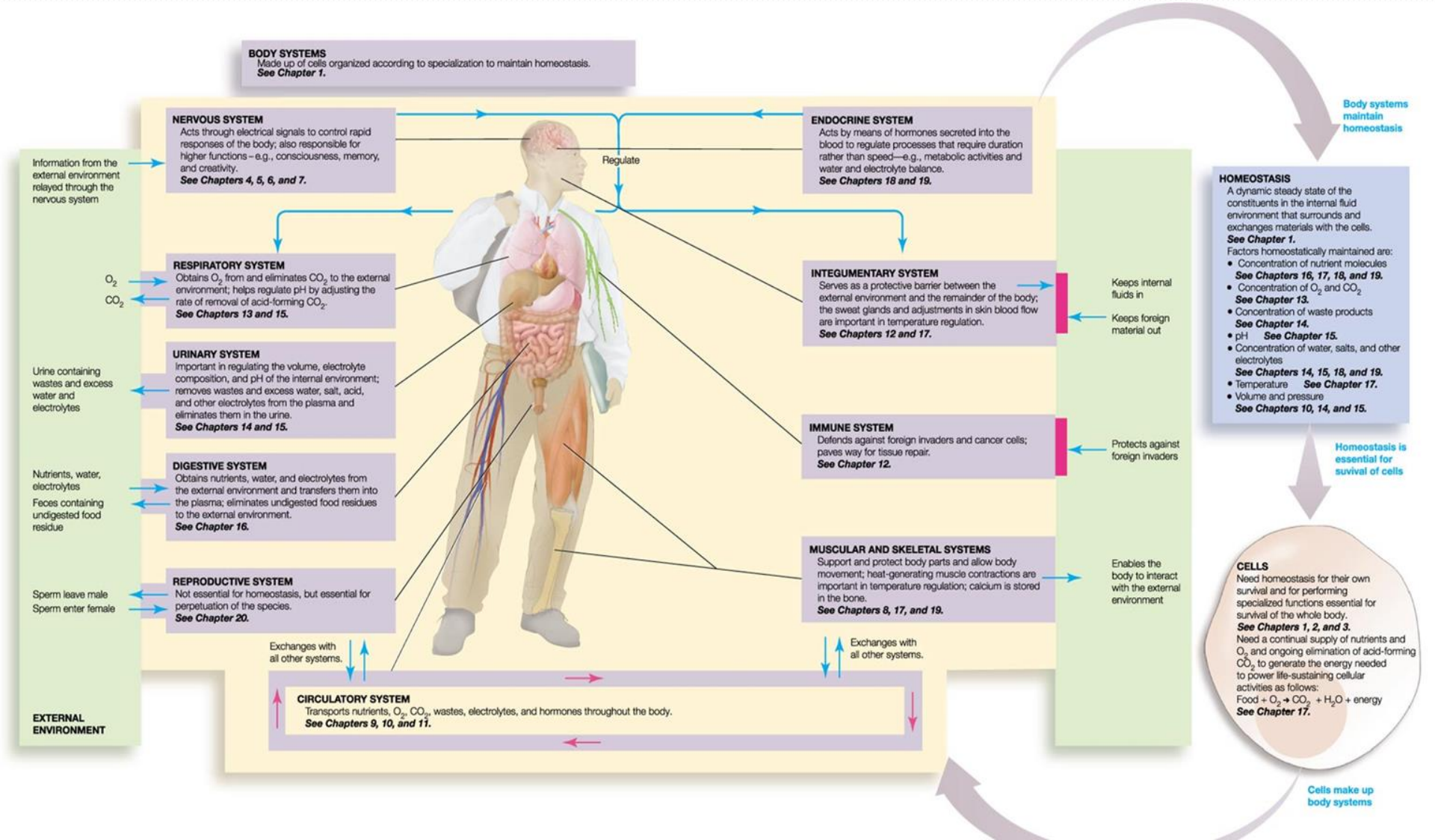


FIGURE 4.3: Negative feedback mechanism – maintenance of water balance.
ADH = Antidiuretic hormone.

TABLE 1–1 Organ Systems of the Body

SYSTEM	MAJOR ORGANS OR TISSUES	PRIMARY FUNCTIONS
Circulatory	Heart, blood vessels, blood (Some classifications also include lymphatic vessels and lymph in this system.)	Transport of blood throughout the body's tissues
Respiratory	Nose, pharynx, larynx, trachea, bronchi, lungs	Exchange of carbon dioxide and oxygen; regulation of hydrogen ion concentration
Digestive	Mouth, pharynx, esophagus, stomach, intestines, salivary glands, pancreas, liver, gallbladder	Digestion and absorption of organic nutrients, salts, and water
Urinary	Kidneys, ureters, bladder, urethra	Regulation of plasma composition through controlled excretion of salts, water, and organic wastes
Musculoskeletal	Cartilage, bone, ligaments, tendons, joints, skeletal muscle	Support, protection, and movement of the body; production of blood cells
Immune	White blood cells, lymph vessels and nodes, spleen, thymus, and other lymphoid tissues	Defense against foreign invaders; return of extracellular fluid to blood; formation of white blood cells
Nervous	Brain, spinal cord, peripheral nerves and ganglia, special sense organs	Regulation and coordination of many activities in the body; detection of changes in the internal and external environments; states of consciousness; learning; cognition
Endocrine	All glands secreting hormones: Pancreas, testes, ovaries, hypothalamus, kidneys, pituitary, thyroid, parathyroid, adrenal, intestinal, thymus, heart, and pineal, and endocrine cells in other locations	Regulation and coordination of many activities in the body, including growth, metabolism, reproduction, blood pressure, electrolyte balance, and others
Reproductive	Male: Testes, penis, and associated ducts and glands Female: Ovaries, fallopian tubes, uterus, vagina, mammary glands	Production of sperm; transfer of sperm to female Production of eggs; provision of a nutritive environment for the developing embryo and fetus; nutrition of the infant
Integumentary	Skin	Protection against injury and dehydration; defense against foreign invaders; regulation of temperature

Role of Body Systems in Homeostasis



Disruptions in Homeostasis

- Can lead to illness and death
- **Pathophysiology**
- Abnormal functioning of the body associated with disease

Disease

- Any condition that prevents the body from working as it should
- As a result the body may fail to maintain homeostasis
- Disease may result from pathogens, abnormal cells, carcinogens, poor nutrition, inherited disorders or risky personal behavior

Causes of disease

- Inherited disorders like Down Syndrome, Cystic Fibrosis, Sickle cell anemia
- Exposure to toxins or carcinogens Lead poisoning, radiation poisoning
- Poor nutrition Scurvy (Vit c deficiency), goiter (Iodine deficiency)
- Organ dysfunction Heart attack ,Diabetes
- High risk behaviors Lung cancer, drug addiction, skin cancer

References

- Human physiology by Lauralee Sherwood, seventh edition
- Text book physiology by Guyton &Hall,14th edition
- Text book of physiology by Linda .s contanzo,third edition