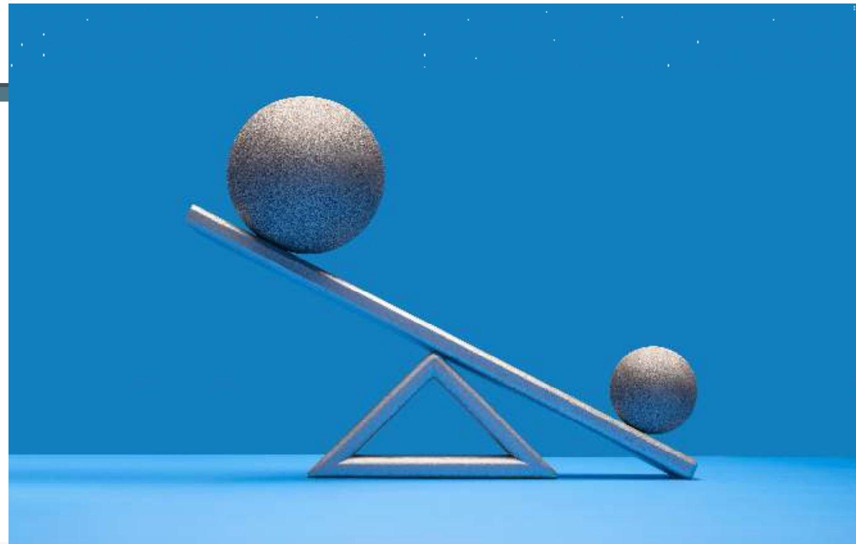
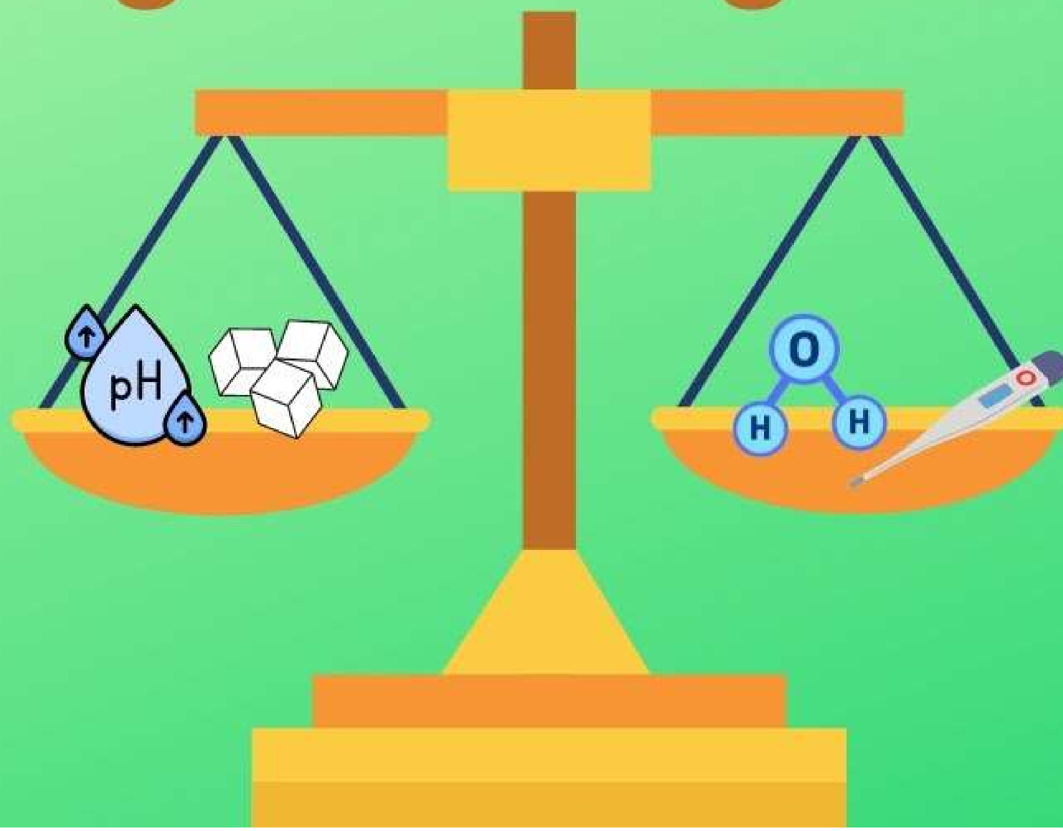
HOMESOSTASIS



D.HAMMOUDI, MD

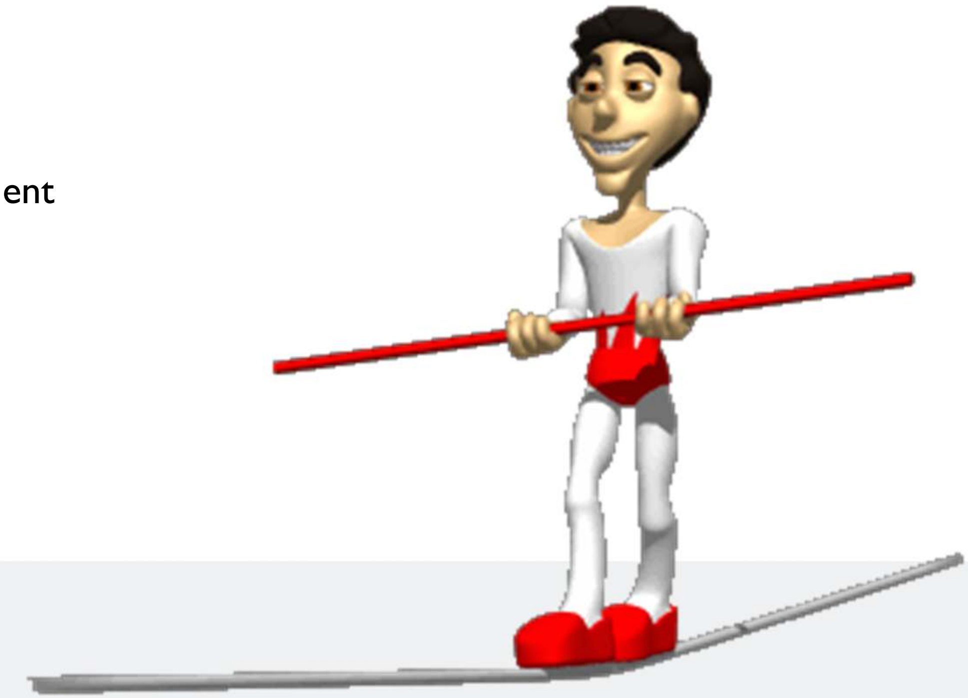
Homeostasis

Keeping Everthing in Balance



HOMEOSTASIS

Regulating the Internal Environment



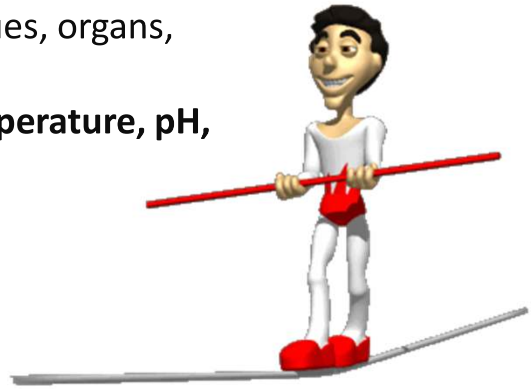
Relative constancy near a setpoint

- Dynamic
    - Energy-consuming
- Negative feedback loops
- Stability of variable is vital to survival
- Interdependence of variables (pyramid)

HOMEOSTASIS

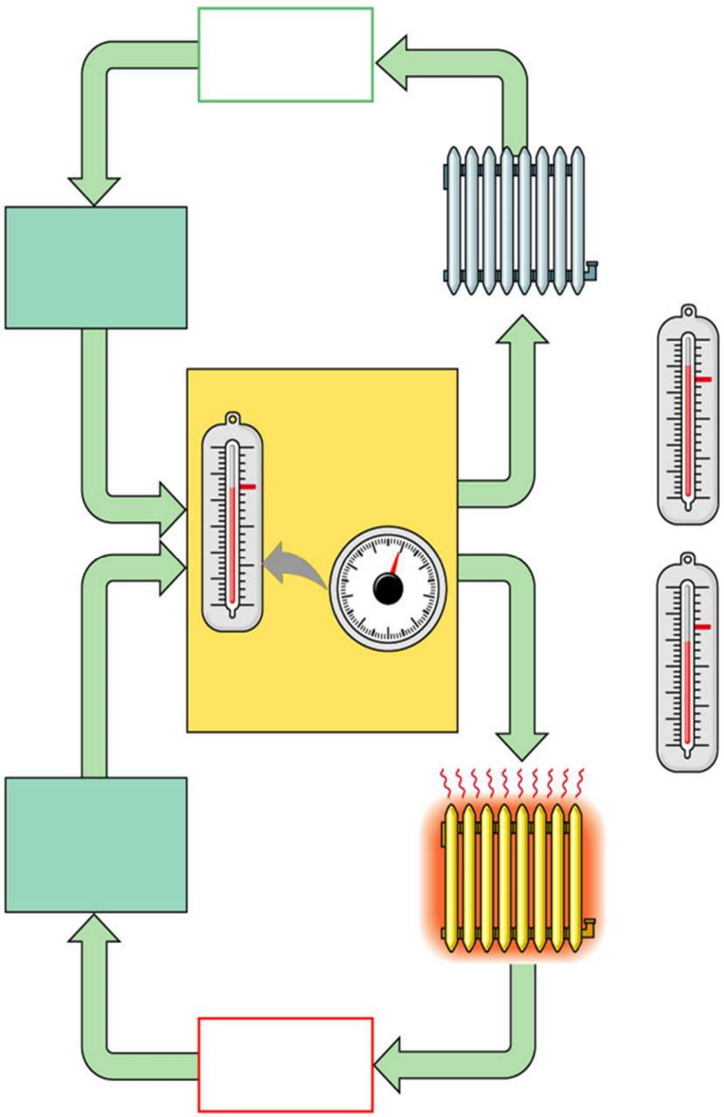
- Homeostasis – ability to maintain a relatively stable internal environment in an ever-changing outside world
  - a dynamic state of equilibrium in which internal conditions remain relative stable (Steady State)
  - The internal environment of the body is in a dynamic state of equilibrium
  - Chemical, thermal, and neural factors interact to maintain homeostasis

- Homeostasis is the process by which living organisms maintain stable internal conditions despite external changes.
- These stable internal conditions are essential for the proper functioning of cells, tissues, organs, and systems within an organism.
- Homeostasis involves the regulation of various physiological variables, **including temperature, pH, blood pressure, blood glucose levels, and electrolyte balance, among others.**



HOMEOSTATIC CONTROL MECHANISMS

- Variables produce a change in the body
- The three interdependent components of control mechanisms:
  - Receptor – monitors the environments and responds to changes (stimuli)
  - Control center – determines the set point at which the variable is maintained
  - Effector – provides the means to respond to stimuli



HOMEOSTATIC CONTROL MECHANISMS

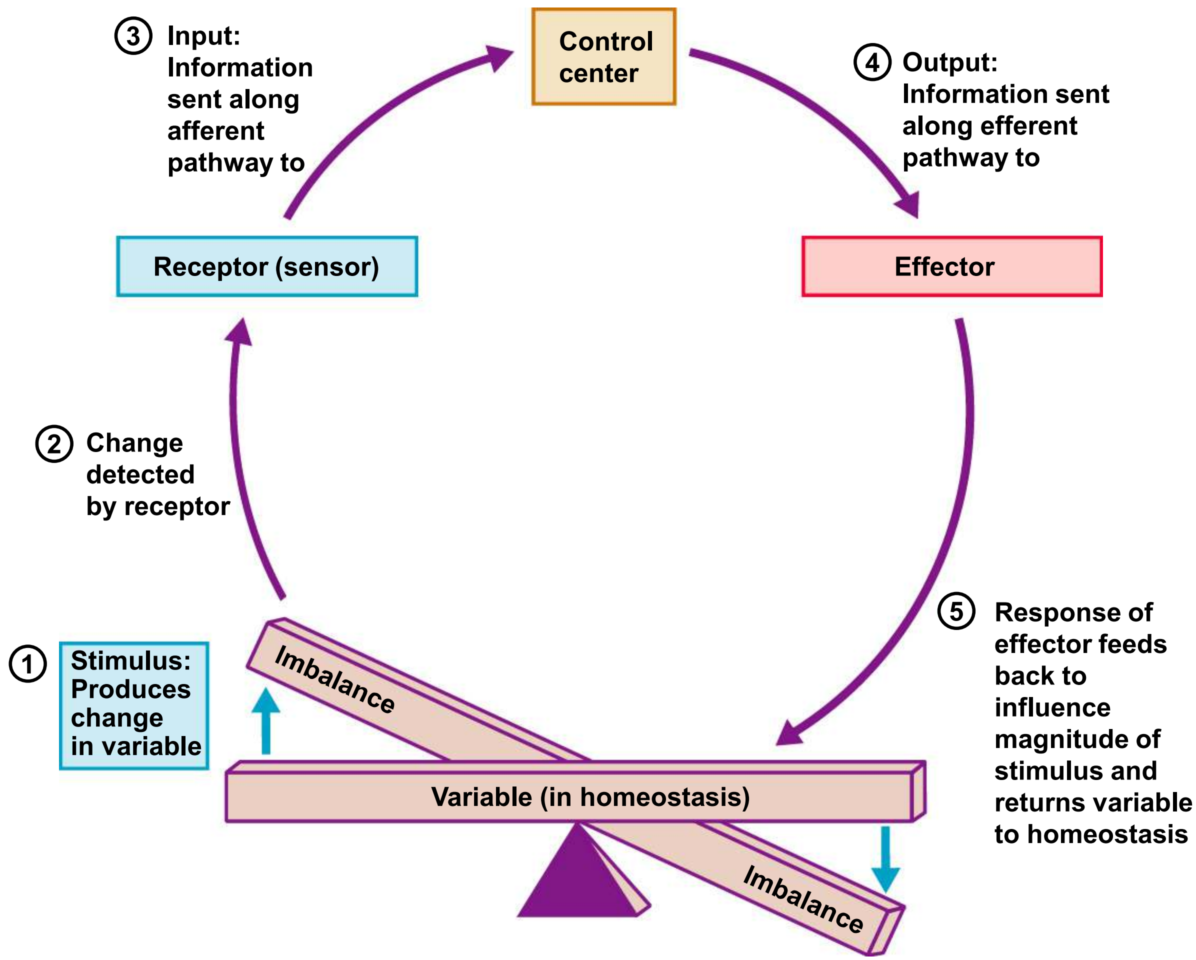
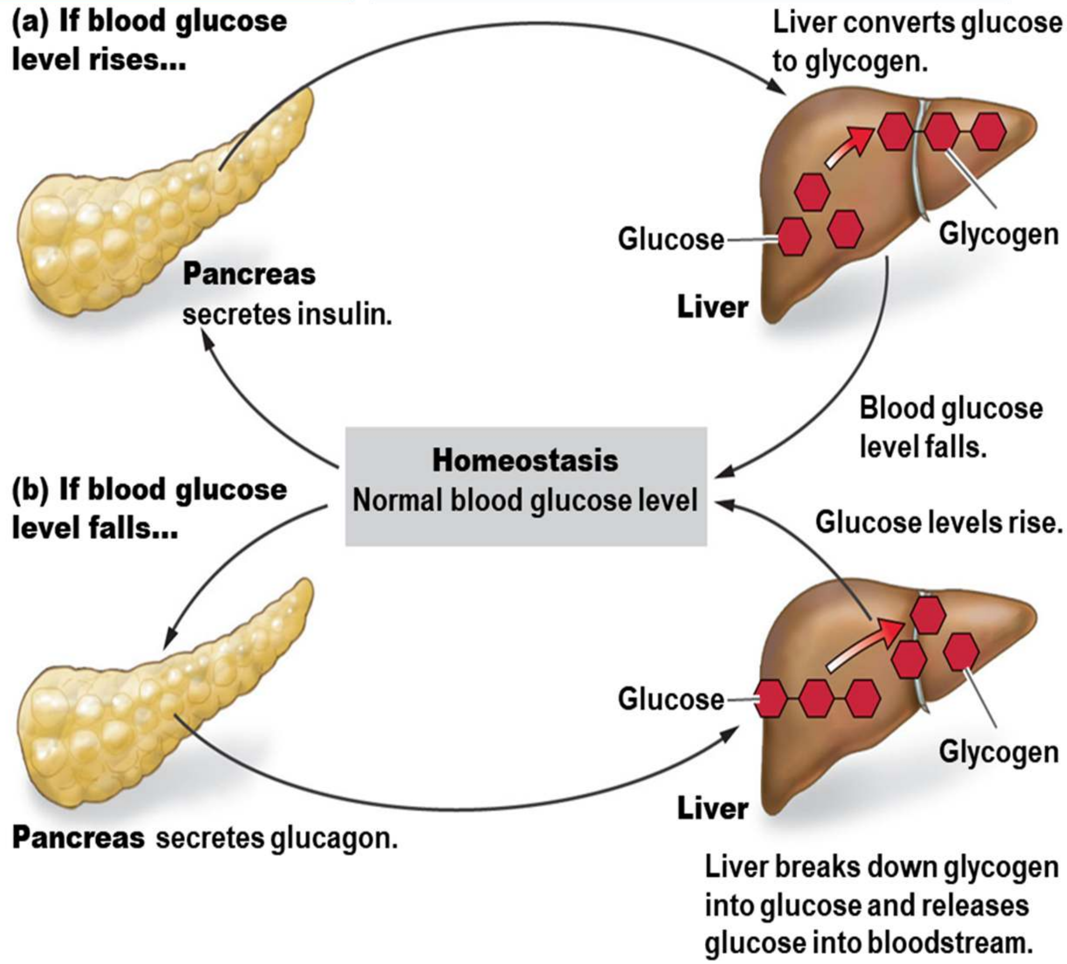
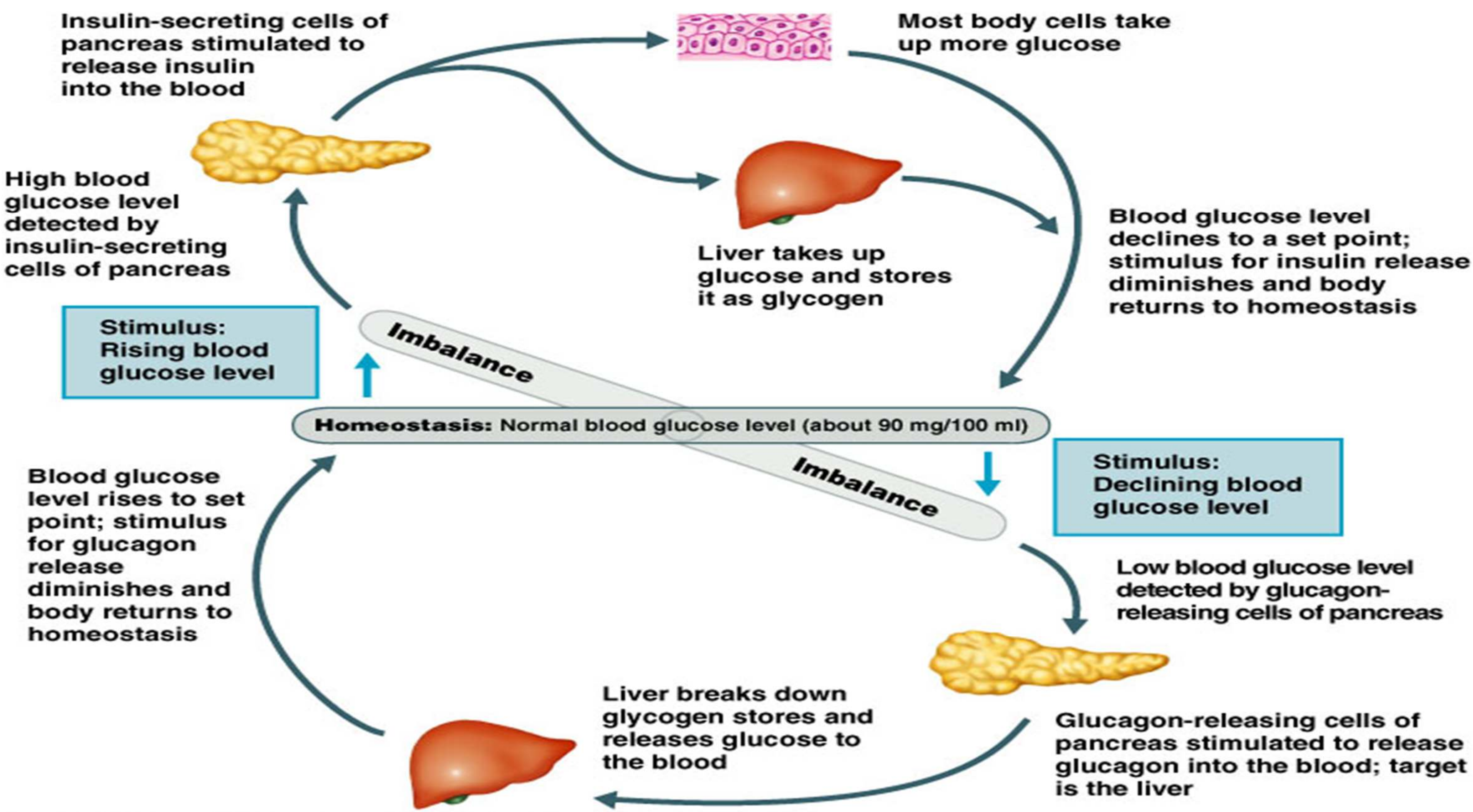


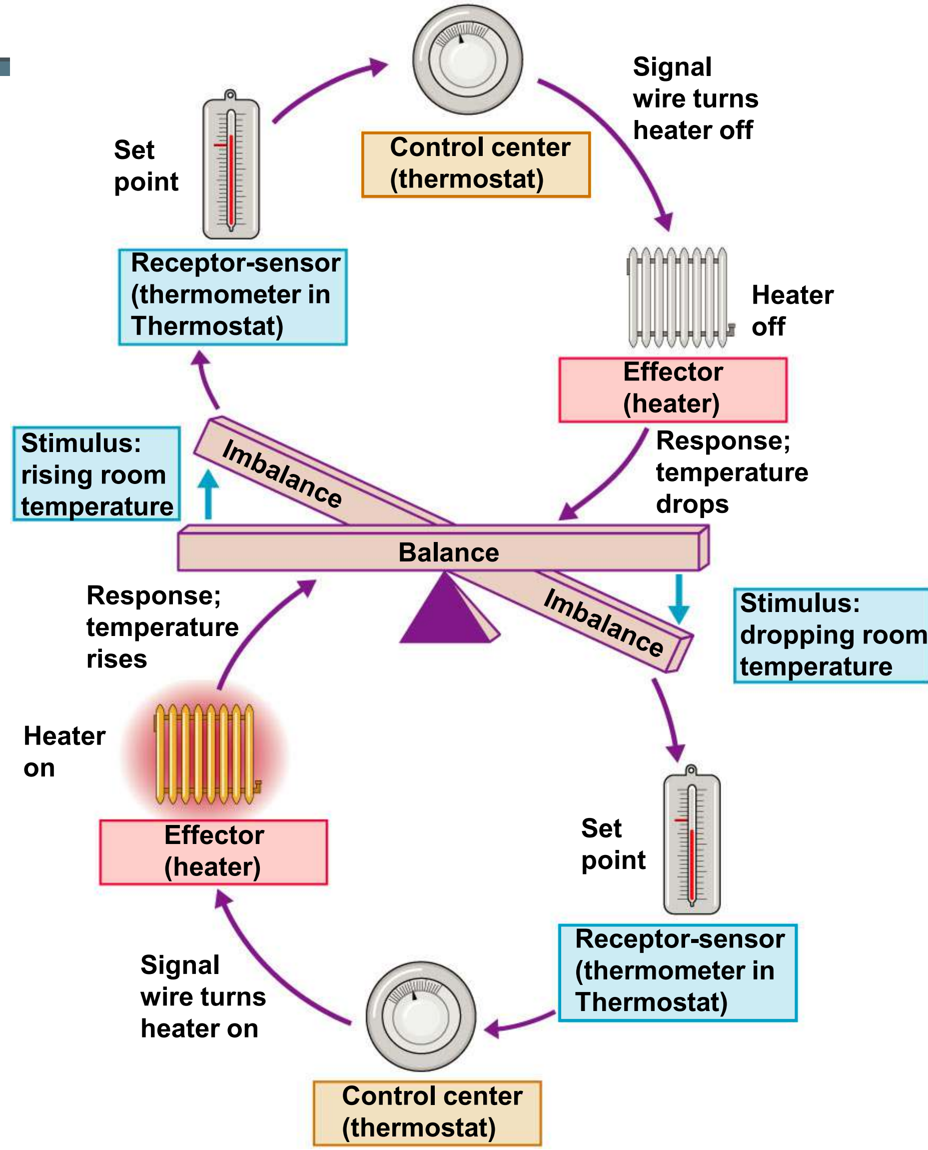
Figure 1.4

NEGATIVE FEEDBACK

- In negative feedback systems, the output shuts off the original stimulus
- Negative feedback is when the outcome of a process inhibits that process.
- This is the most common type of feedback mechanism in which the response opposes the initial change in the variable, thus maintaining stability.
- For example, when body temperature rises above normal, negative feedback mechanisms kick in to lower it back to the set point.
- Example: Regulation of room temperature




Insulin-secreting cells of pancreas stimulated to release insulin into the blood
Most body cells take up more glucose
High blood glucose level detected by insulin-secreting cells of pancreas
Liver takes up glucose and stores it as glycogen
Blood glucose level declines to a set point; stimulus for insulin release diminishes and body returns to homeostasis
Stimulus: Rising blood glucose level
Imbalance
Homeostasis: Normal blood glucose level (about 90 mg/100 ml)
Imbalance
Stimulus: Declining blood glucose level
Blood glucose level rises to set point; stimulus for glucagon release diminishes and body returns to homeostasis
Low blood glucose level detected by glucagon-releasing cells of pancreas
Liver breaks down glycogen stores and releases glucose to the blood
Glucagon-releasing cells of pancreas stimulated to release glucagon into the blood; target is the liver



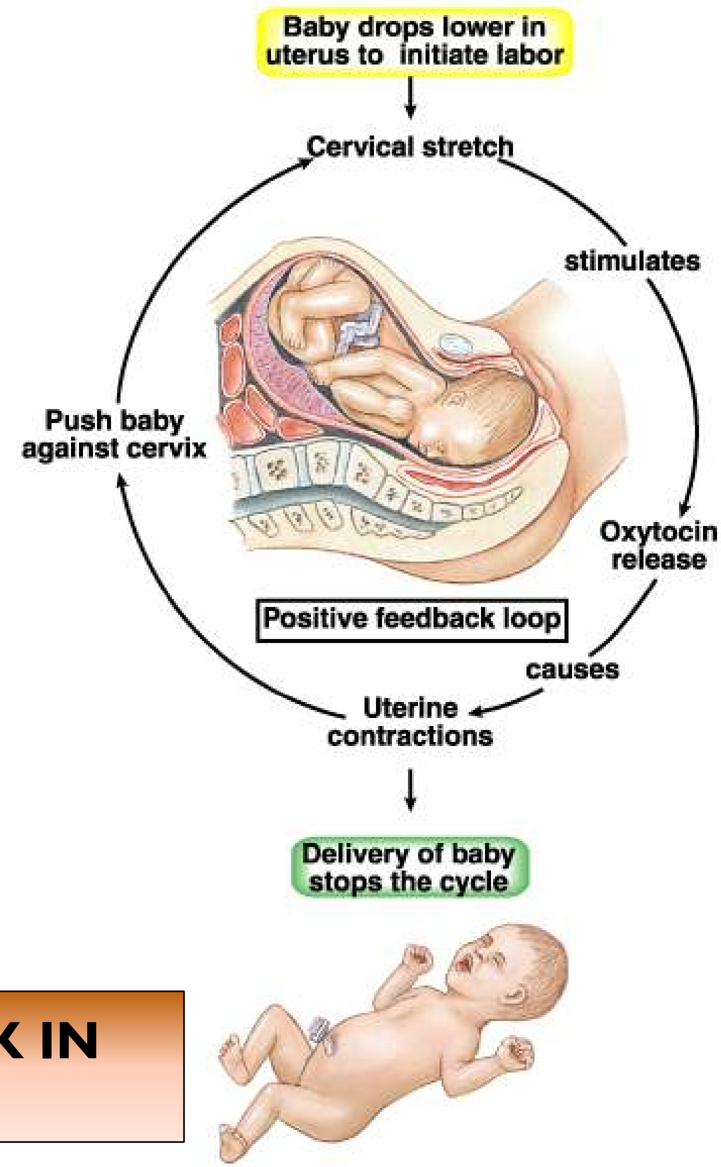
Set point
Control center (thermostat)
Signal wire turns heater off
Receptor-sensor (thermometer in Thermostat)
Heater off
Effector (heater)
Response; temperature drops
Stimulus: rising room temperature
Imbalance
Balance
Imbalance
Stimulus: dropping room temperature
Response; temperature rises
Heater on
Effector (heater)
Set point
Receptor-sensor (thermometer in Thermostat)
Signal wire turns heater on
Control center (thermostat)

Figure 1.5

Positive Feedback

- Positive Feedback: In this type of feedback mechanism, the response amplifies the initial change, leading to further deviation from the set point.
- While positive feedback loops are less common in maintaining homeostasis, they play important roles in processes such as childbirth and blood clotting.

- Positive Feedback Loop
  - Example: childbirth
  - Pressure of an infant's head on cervix
  - Stimulates stretch receptors
  - Receptors signal to brain to release oxytocin
  - Presence of oxytocin intensifies labor contractions
  - As baby moves, pressure creates more signals for oxytocin
  - Birth of infant releases pressure & signal for oxytocin

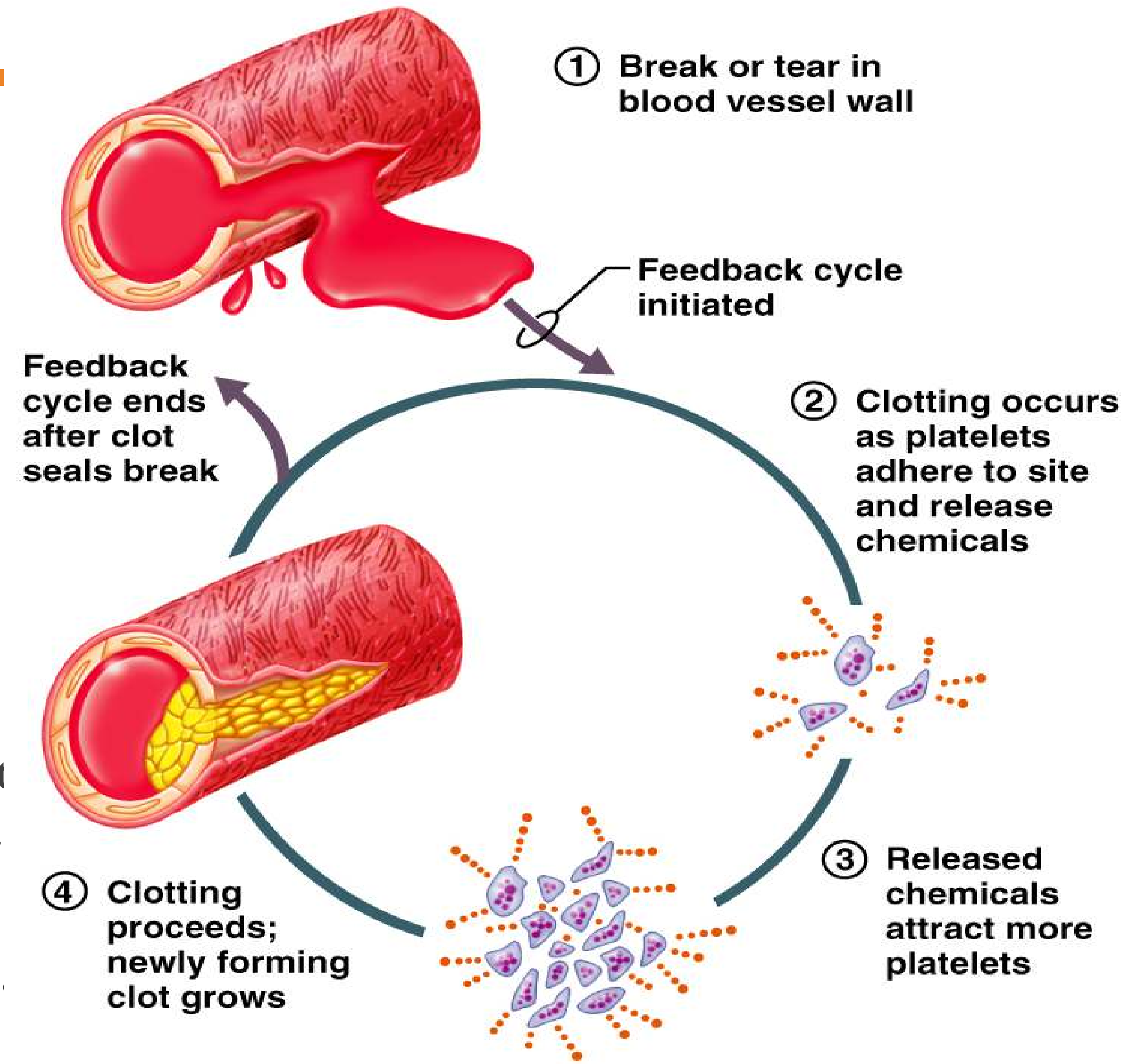


POSITIVE FEEDBACK IN CHILDBIRTH

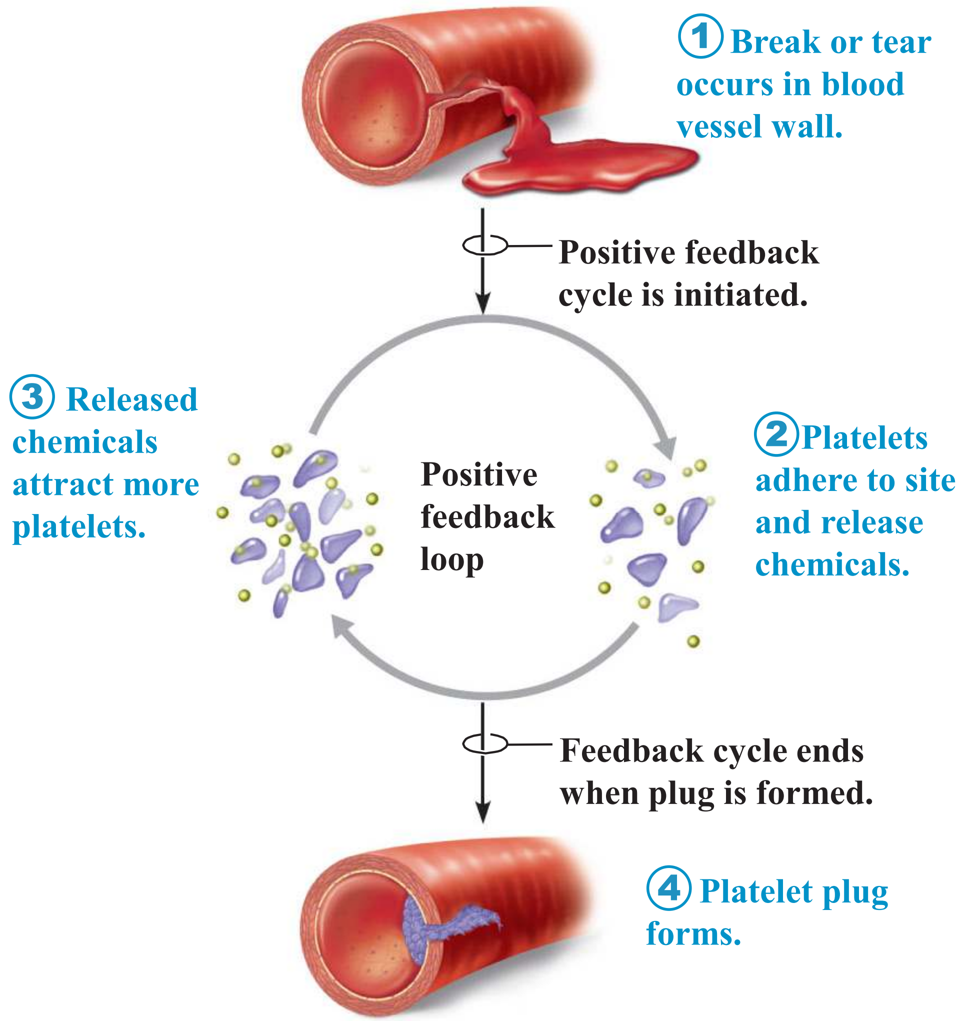
POSITIVE FEEDBACK

- When a blood vessel is damaged, platelets adhere to the site and release chemicals that attract more platelets.
- This leads to the formation of a platelet plug, which activates further clotting factors and accelerates the clotting process.

- In positive feedback systems, the out enhances or exaggerates the origina stimulus
- Example: Regulation of blood clottin



SUMMARY OF THE POSITIVE FEEDBACK MECHANISM REGULATING FORMATION OF A PLATELET PLUG.



SET POINT

- Homeostasis involves maintaining internal conditions around a specific set point, which represents the optimal or ideal level of a physiological variable.
- The body continuously monitors these variables and makes adjustments as needed to keep them within a narrow range around the set point.

Regulatory Systems:

- Homeostasis is regulated by various physiological systems, including the nervous system, endocrine system, and immune system.
- These systems work together to detect deviations from the set point and initiate appropriate responses to restore balance.

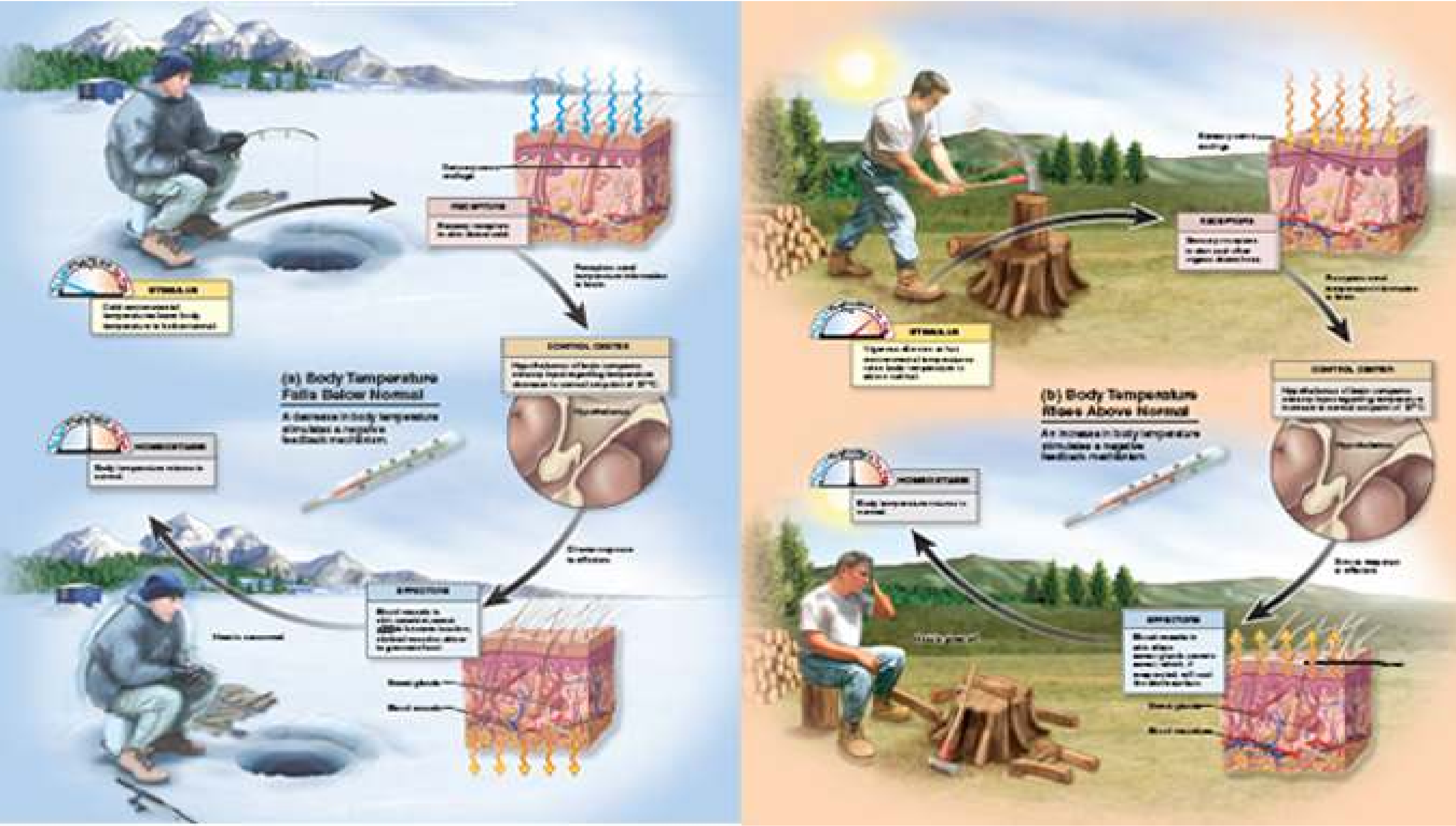
Examples of homeostatic processes include:

- **Thermoregulation:** Regulation of body temperature to maintain it within a narrow range despite fluctuations in environmental temperature.
    - **Body Temperature Regulation:** When body temperature rises, thermoreceptors in the skin detect the increase and send signals to the hypothalamus in the brain.
    - **The hypothalamus** then stimulates the sweat glands to produce sweat, which evaporates and cools the body.
    - As body temperature continues to rise, more sweat is produced, leading to further cooling of the body.

- **Blood Glucose Regulation:** **Control of blood glucose levels through the actions of insulin and glucagon to prevent hyperglycemia or hypoglycemia**.

- **pH Balance:** Maintenance of the body's acid-base balance to keep the pH of bodily fluids within a specific range (7.4).

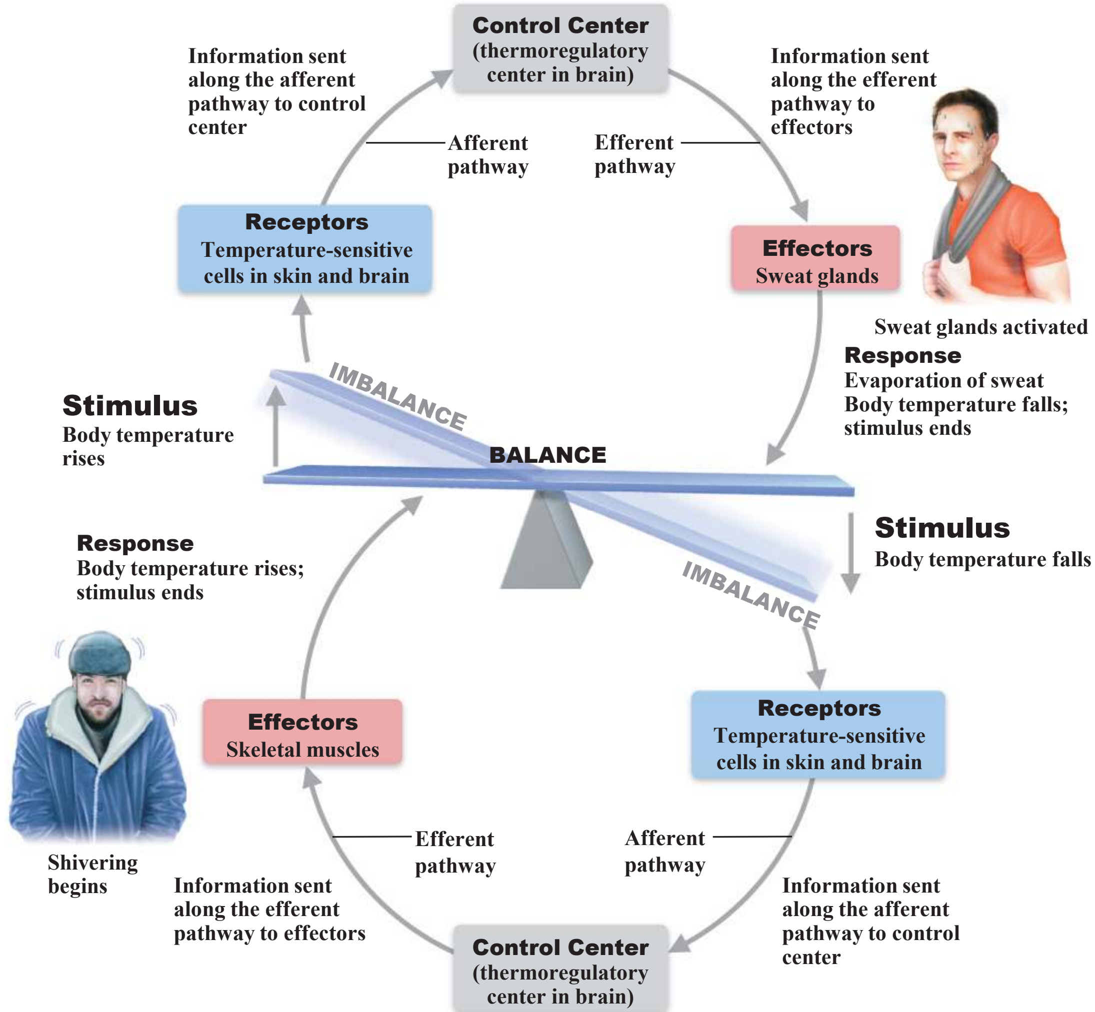
- **Fluid and Electrolyte Balance:** Regulation of water and electrolyte levels in the body to ensure proper hydration and electrolyte concentrations.

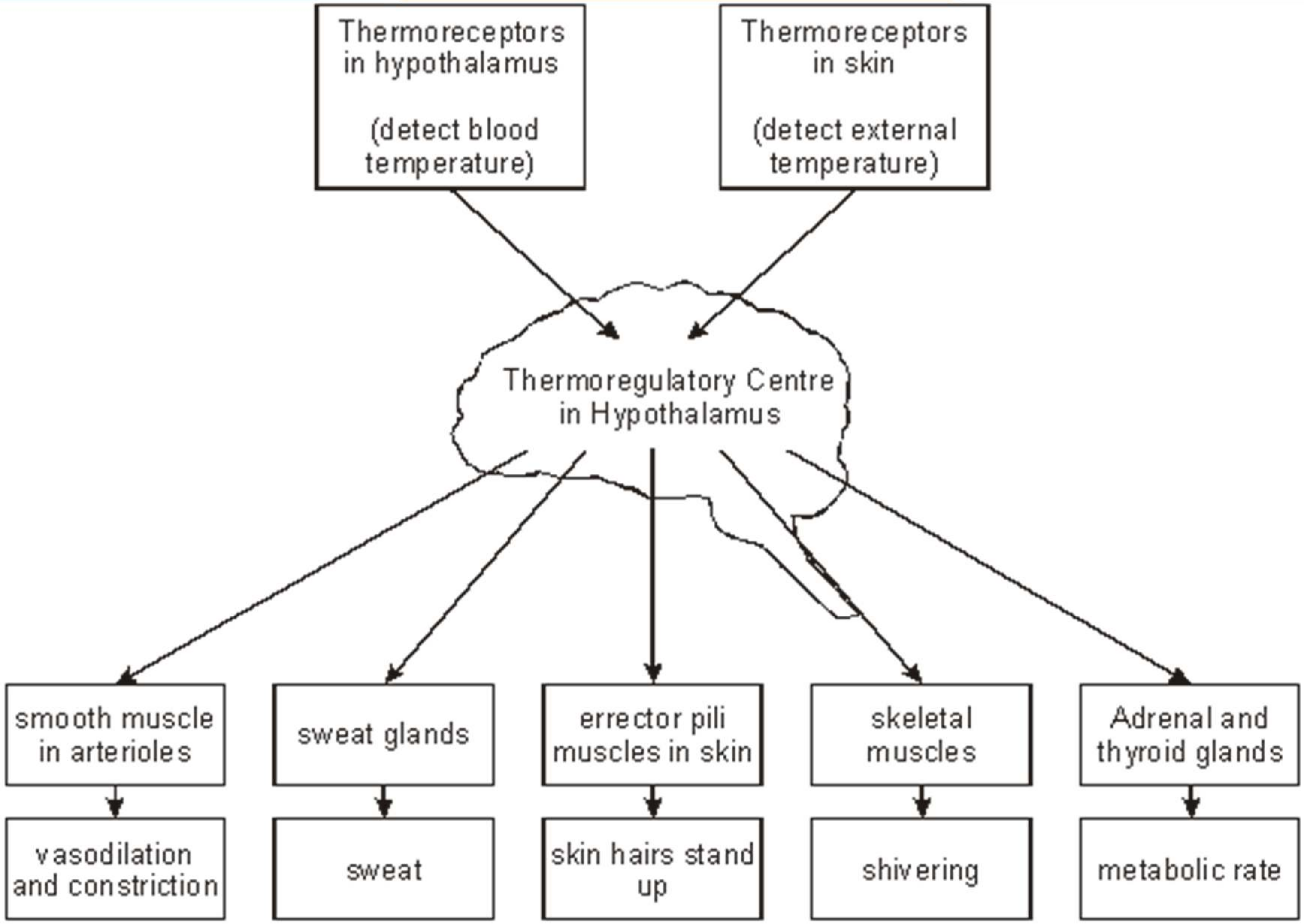


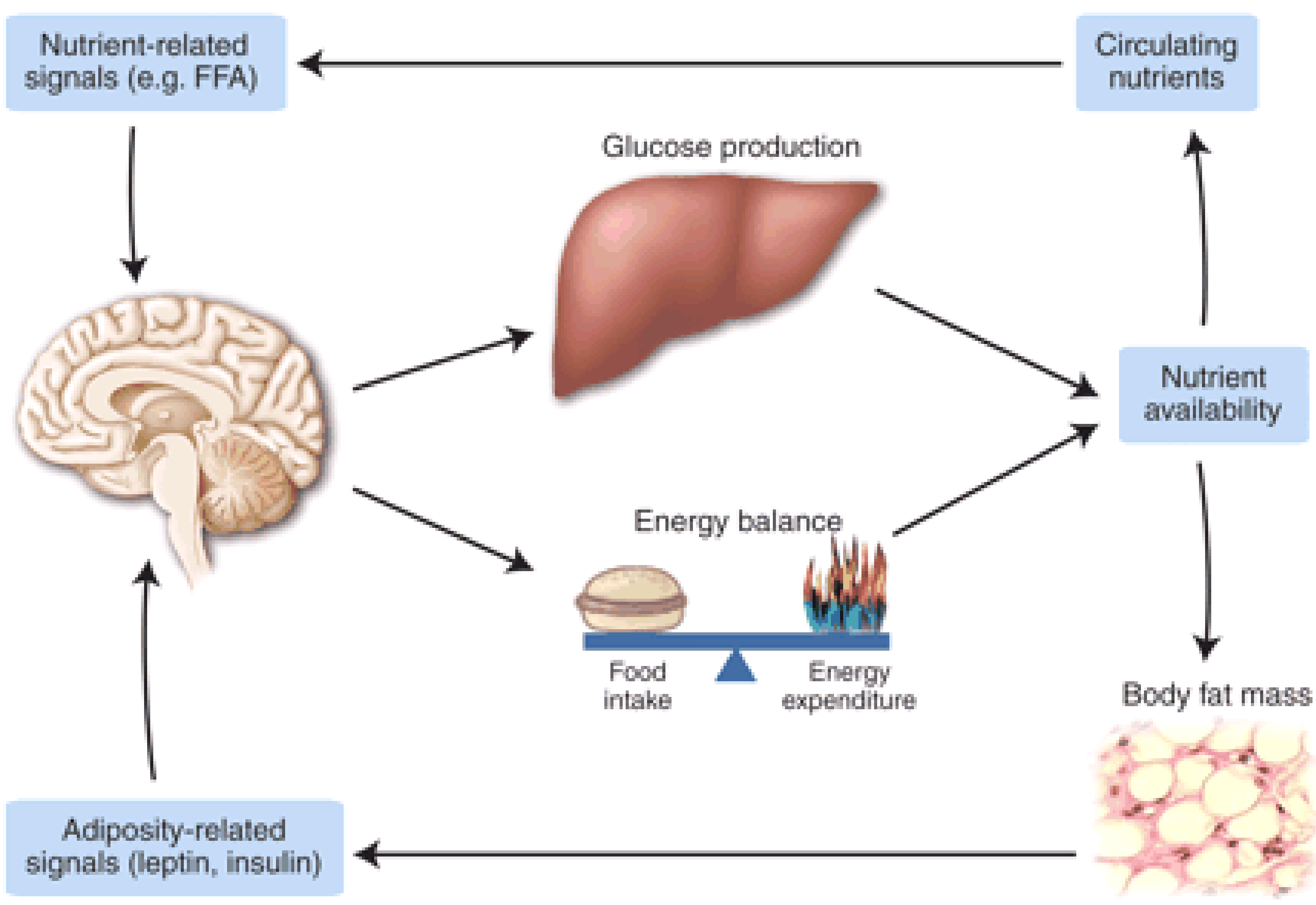
(a) Body Temperature Falls Below Normal
A decrease in body temperature stimulates a negative feedback mechanism.
(b) Body Temperature Rises Above Normal
An increase in body temperature stimulates a negative feedback mechanism.

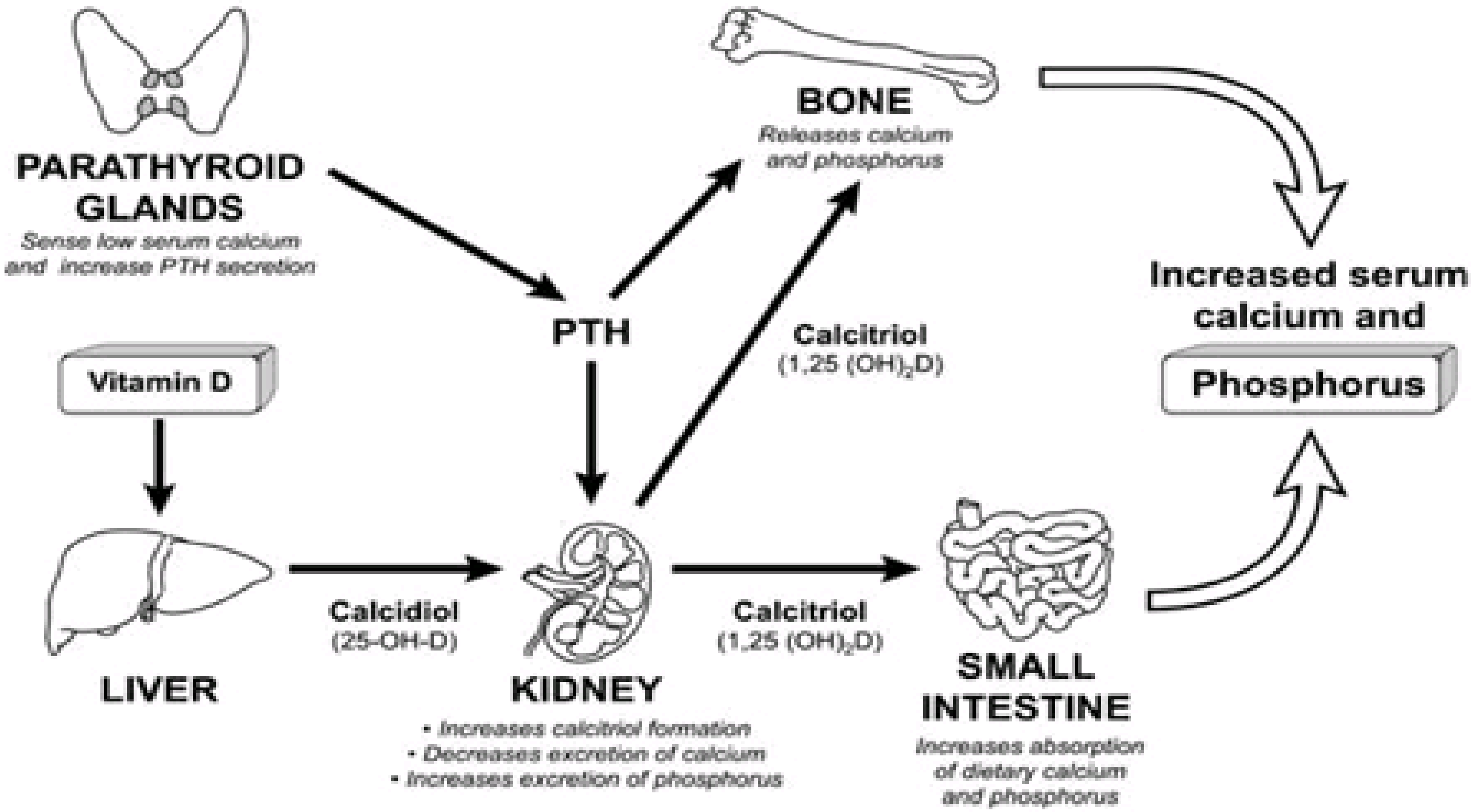
Effector	Response to low temperature	Response to high temperature
Smooth muscles in peripheral arterioles in the skin.	• Muscles contract causing <u>vasoconstriction</u>. • Less heat is carried from the core to the surface of the body, maintaining core temperature. • Extremities can turn blue and feel cold and can even be damaged (frostbite). •	• Muscles relax causing <u>vasodilation</u>. • More heat is carried from the core to the surface, where it is lost by convection and radiation. • Skin turns red.
Sweat glands	• No sweat produced.	• Glands secrete sweat onto surface of skin, where it evaporates. • This is an endothermic process and water has a high latent heat of evaporation, so it takes heat from the body.
Erector pili muscles in skin (attached to skin hairs)	• Muscles contract, raising skin hairs and trapping an insulating layer of still, warm air next to the skin. • Not very effective in humans, just causing "goosebumps".	• Muscles relax, lowering the skin hairs and allowing air to circulate over the skin, encouraging convection and evaporation.
Skeletal muscles	• Muscles contract and relax repeatedly, generating heat by friction and from metabolic reactions.	• No shivering.
Adrenal and thyroid glands	• Glands secrete adrenaline and thyroxine respectively, which increase the metabolic rate in different tissues, especially the liver, so generating heat.	• Glands stop releasing adrenaline and thyroxine.
Behaviour	• Curling up, huddling, finding shelter, putting on more clothes. •	• Stretching out, finding shade, swimming, removing clothes.

FIGURE 1.5 REGULATION OF BODY TEMPERATURE BY A NEGATIVE FEEDBACK MECHANISM.

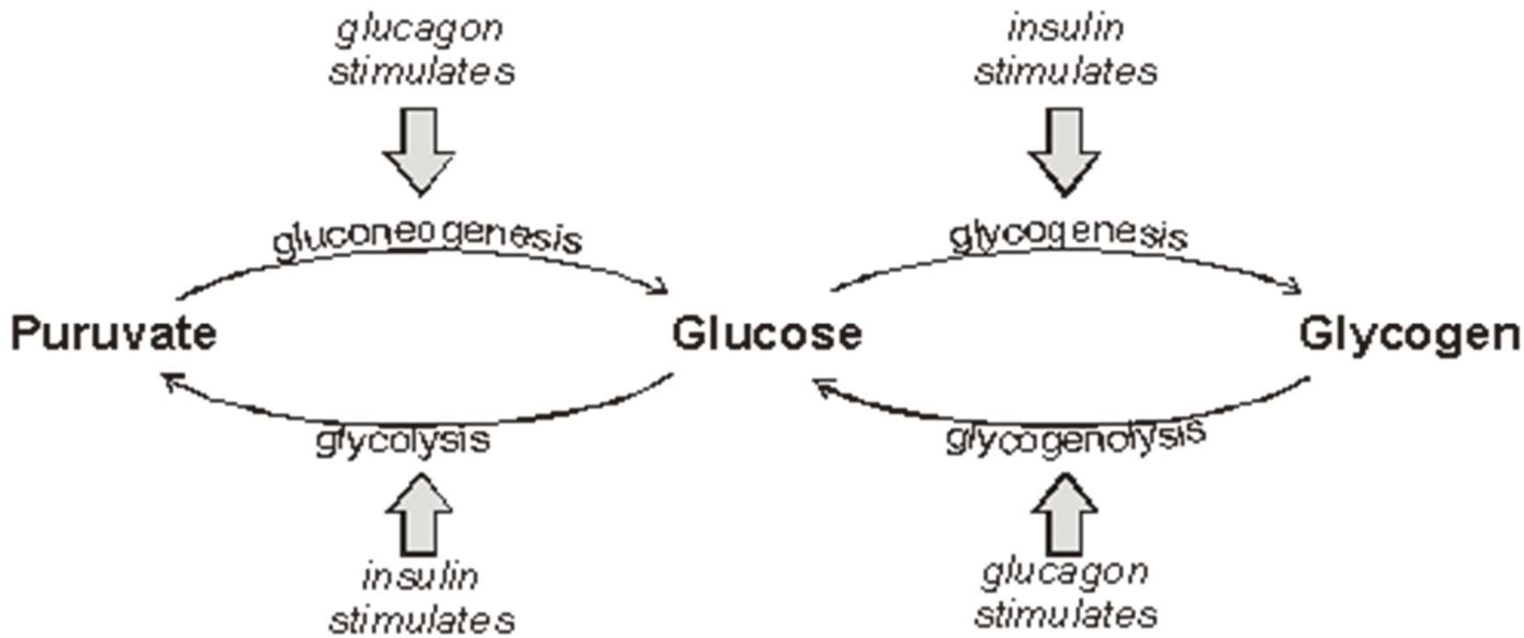



Thermoreceptors in hypothalamus
(detect blood temperature)
Thermoreceptors in skin
(detect external temperature)
Thermoregulatory Centre in Hypothalamus
smooth muscle in arterioles
sweat glands
errector pili muscles in skin
skeletal muscles
Adrenal and thyroid glands
vasodilation and constriction
sweat
skin hairs stand up
shivering
metabolic rate


Nutrient-related signals (e.g. FFA)
Circulating nutrients
Glucose production
Nutrient availability
Energy balance
Food intake
Energy expenditure
Body fat mass
Adiposity-related signals (leptin, insulin)


PARATHYROID
GLANDS
Sense low serum calcium
and increase PTH secretion
PTH
BONE
Releases calcium
and phosphorus
Increased serum
calcium and
Phosphorus
Calcitriol
(1,25 $(OH)_2D$)
Vitamin D
LIVER
Calcidiol
(25-OH-D)
KIDNEY
• Increases calcitriol formation
• Decreases excretion of calcium
• Increases excretion of phosphorus
Calcitriol
(1,25 $(OH)_2D$)
SMALL
INTESTINE
Increases absorption
of dietary calcium
and phosphorus

ANOTHER FEEDBACK



HOMEOSTATIC IMBALANCE

- Disturbance of homeostasis or the body's normal equilibrium
- Overwhelming the usual negative feedback mechanisms allows destructive positive feedback mechanisms to take over

DANGEROUS POSITIVE FEEDBACK

- **Positive feedback loops are typically considered dangerous when they lead to a self-reinforcing or escalating process that can result in extreme or harmful outcomes.**

EXAMPLES OF DANGEROUS POSITIVE FEEDBACK LOOPS:

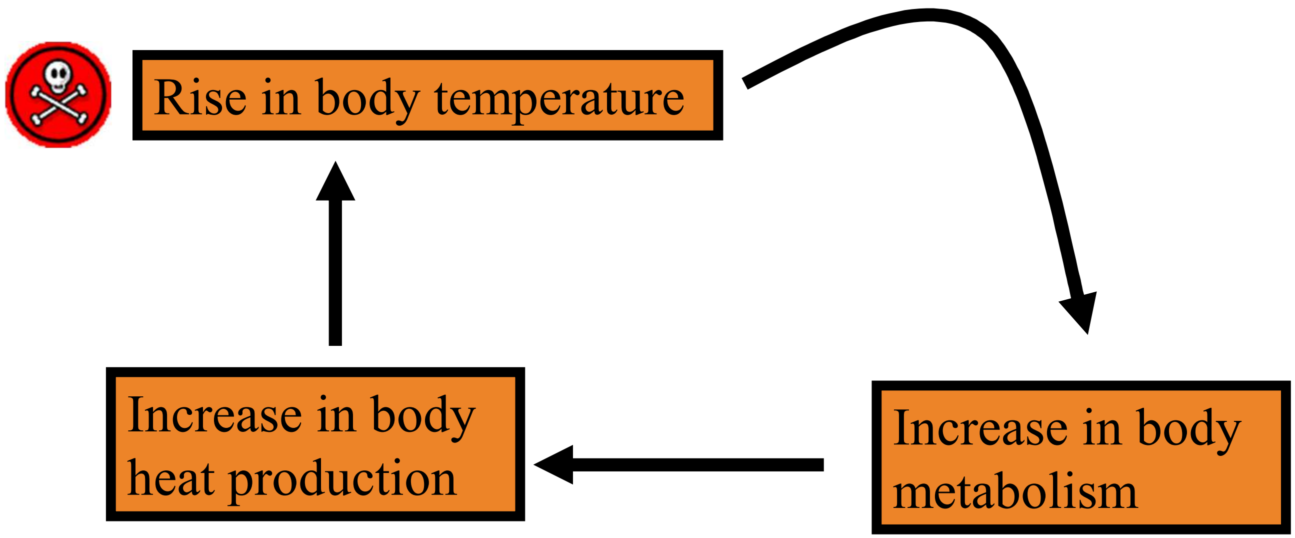
1. **Hypothalamic-Pituitary-Adrenal (HPA) Axis Dysfunction**:
   1. **In response to stress**, the hypothalamus secretes corticotropin-releasing hormone (CRH), which stimulates the anterior pituitary gland to release adrenocorticotropic hormone (ACTH).
      - **ACTH, in turn, stimulates the adrenal glands to produce cortisol, a stress hormone.**
   2. In a dangerous positive feedback loop, chronic stress or prolonged activation of the HPA axis can lead to excessive cortisol production.
      - **High levels of cortisol can further stimulate the release of CRH and ACTH, perpetuating the stress response**.
   3. **Prolonged exposure to high levels of cortisol can have detrimental effects on various physiological systems, including the immune system, cardiovascular system, and metabolism, contributing to conditions such as anxiety, depression, obesity, and cardiovascular disease.**

2. **Blood Clotting Cascade**:
   1. When a blood vessel is injured, platelets adhere to the site of injury and release chemicals that activate the blood clotting cascade.
   2. The blood clotting cascade involves a series of enzymatic reactions that ultimately lead to the formation of a blood clot to stop bleeding.
   3. **In a dangerous positive feedback loop, excessive activation of the blood clotting cascade or impaired clot dissolution can lead to the formation of excessive blood clots (thrombosis).**
   4. **These blood clots can obstruct blood flow to vital organs, leading to conditions such as heart attack, stroke, or pulmonary embolism**.

EXAMPLES OF DANGEROUS POSITIVE FEEDBACK LOOPS:

1. **Fever Response**:
   1. Fever is a physiological response to infection or inflammation, mediated by the release of pyrogens (fever-inducing substances) such as cytokines.
   2. **In a dangerous positive feedback loop, the release of pyrogens can stimulate the hypothalamus to raise the body's temperature set point, leading to fever**.
   3. **While fever can help the body fight infection by inhibiting the growth of pathogens and enhancing immune function, excessively high temperatures can be harmful, causing dehydration, electrolyte imbalances, and metabolic disturbances.**

DANGEROUS POSITIVE FEEDBACK



Dangerous positive feedback loops can lead to runaway processes that threaten the stability or health of an organism.

DANGEROUS POSITIVE FEEDBACK

1. **Fever**: While fever is a normal response to infection, it can become dangerous if the body's temperature regulation mechanisms fail to control it. In severe cases, a fever can rise to dangerous levels, leading to dehydration, seizures, or organ damage.

2. **Blood Clotting**: While blood clotting is essential for wound healing, unchecked clotting can lead to the formation of blood clots (thrombosis) that block blood flow to vital organs, causing heart attacks, strokes, or pulmonary embolisms.

3. **Cytokine Storm**: In some cases of infection or immune response, the body can produce an excessive amount of cytokines (small proteins that regulate immune responses). This can trigger a cytokine storm, where the immune system attacks healthy tissues and organs, leading to systemic inflammation and organ failure.

1. **Vicious Cycle of Inflammation**: Inflammation is a normal response to tissue injury or infection. However, if inflammation persists or becomes chronic, it can lead to tissue damage and further inflammation, creating a vicious cycle that exacerbates the initial problem.

2. **Hemorrhage**: Excessive bleeding can trigger a positive feedback loop where decreasing blood volume leads to reduced blood pressure, which in turn reduces blood flow to vital organs and further decreases blood volume. This cycle can result in hemorrhagic shock and organ failure.

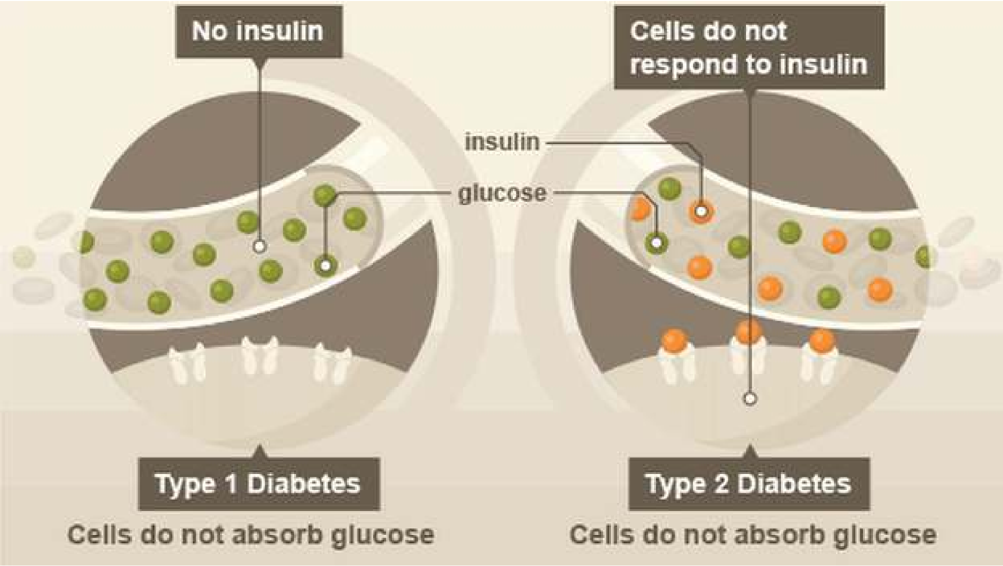
3. **Hyperglycemia**: In diabetic ketoacidosis (DKA), high blood sugar levels trigger the release of counter-regulatory hormones (e.g., glucagon, cortisol, adrenaline), which further increase blood sugar levels. This positive feedback loop can lead to dangerously high blood sugar levels and metabolic acidosis.

1. **Heart Failure**: In heart failure, decreased cardiac output leads to reduced blood flow to the kidneys. This triggers the **renin-angiotensin-aldosterone system (RAAS)** to increase blood pressure, but it can also lead to fluid retention, worsening heart failure and further reducing cardiac output.

2. **Electrolyte Imbalances**: In conditions such as **hypercalcemia or hyperkalemia, high levels of calcium or potassium in the blood can disrupt normal cellular function**, leading to further increases in blood levels of these electrolytes through various mechanisms.

DIABETES

- Your body digests food and breaks it down into glucose--absorbed into the bloodstream
- This glucose fuels cellular respiration
- Individual cells convert glucose to ATP to fuel cell processes
- If your cells can't absorb enough glucose, health problems arise
- **Insulin** helps move sugar from our bloodstream into our body cells



DIABETES

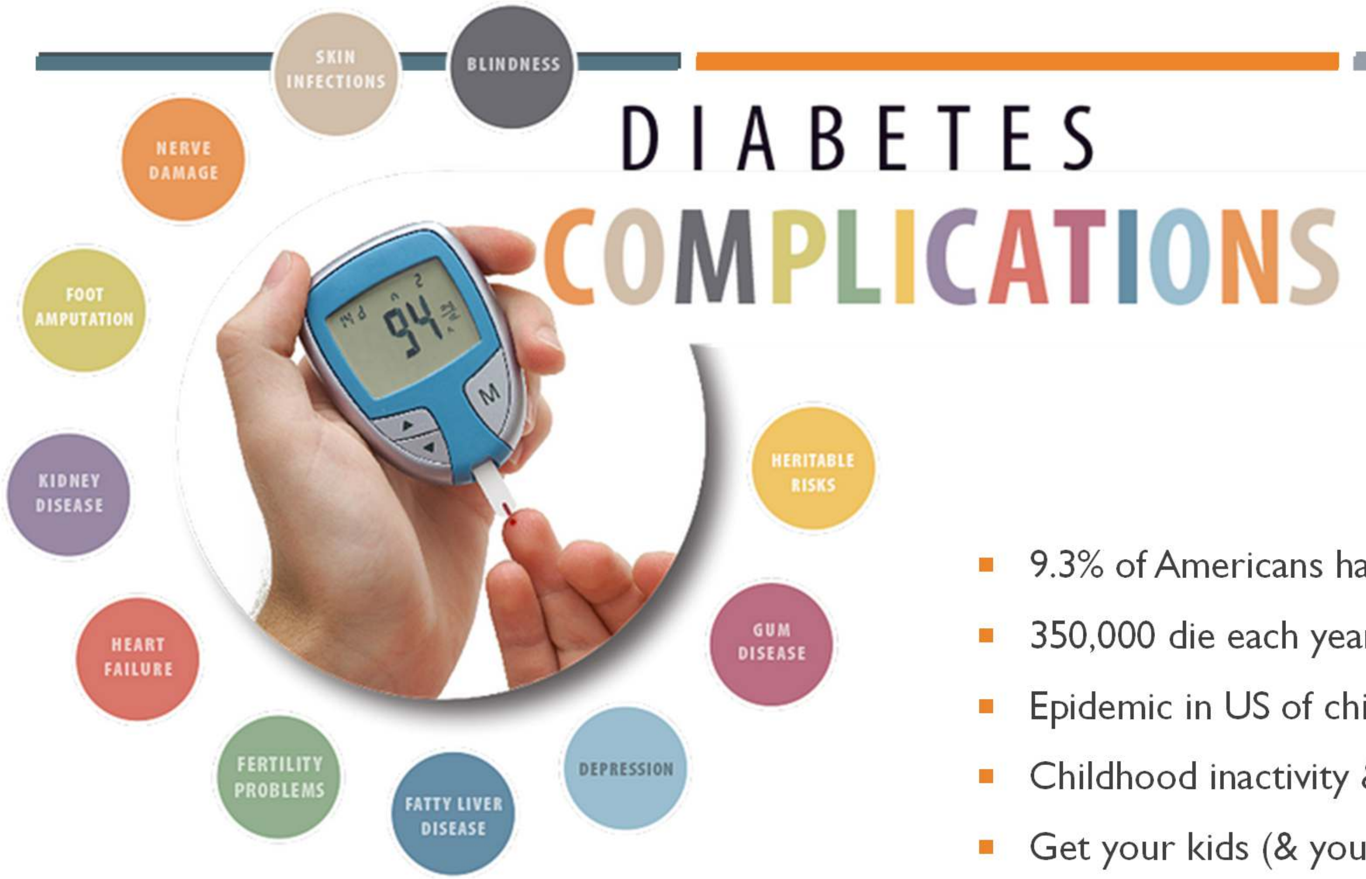
Type 1 Diabetes

- No insulin produced
- “Juvenile onset”– usually diagnosed before age 15
- Beta cells in pancreas are destroyed by immune system
- Requires insulin supplementation
- Ex. Nick Jonas

Type 2 Diabetes

- Body doesn’t respond to insulin produced
- “Adult onset”– usually diagnosed around age 40
- Can be inherited and is often associated with obesity
- Can often be treated by improvements in diet,

  exercise, and weight loss
- Ex. Drew Carey



- 9.3% of Americans have diabetes
- 350,000 die each year
- Epidemic in US of children with Type 2 Diabetes
- Childhood inactivity & obesity are major factors
- Get your kids (& yourself) outside!
- No cure for diabetes, but early treatment is essential

OTHER EXAMPLES OF FEEDBACK POSITIVE

1.Fever: When the body detects an infection, it increases its core temperature to create an environment that is less favorable for the growth of pathogens.

- As the body temperature rises, metabolic processes speed up, leading to even higher temperatures and a stronger immune response.

2. **Action Potential:** In neurons, depolarization of the cell membrane leads to the opening of voltage-gated sodium channels, allowing sodium ions to enter the cell. This depolarizes the membrane further, leading to the opening of more sodium channels and a rapid increase in membrane potential.

3.Uterine Contractions during Menstruation: Prostaglandins released from the uterine lining during menstruation stimulate further contractions of the uterine muscles. These contractions help expel the menstrual fluid from the uterus.

4.Milk Production (Lactation): When a baby suckles at the breast, it stimulates nerve endings in the nipple, triggering the release of oxytocin and prolactin hormones. Oxytocin causes the contraction of the mammary glands, expelling milk, while prolactin stimulates further milk production.

5.Blood Pressure Regulation: When blood pressure drops, baroreceptors in the walls of blood vessels detect the decrease and send signals to the brain. The brain then activates the sympathetic nervous system, which increases heart rate and constricts blood vessels, leading to a further increase in blood pressure.

Ovulation: As a follicle in the ovary matures, it releases increasing levels of estrogen hormone.

- High levels of estrogen trigger a surge in luteinizing hormone (LH), which in turn induces ovulation, the release of a mature egg from the ovary.

MORE NEGATIVE FEEDBACK

1.Thermoregulation: When body temperature rises above the set point, thermoreceptors in the skin and hypothalamus detect the increase and trigger mechanisms to cool the body, such as vasodilation (expanding blood vessels near the skin's surface to release heat) and sweating.

2.Blood Glucose Regulation: After a meal, blood glucose levels rise. This increase stimulates the release of insulin from the pancreas, which promotes the uptake of glucose by cells for energy and storage as glycogen in the liver and muscles. As blood glucose levels decrease, insulin secretion decreases as well.

3.Blood Pressure Regulation: When blood pressure rises above normal, baroreceptors in blood vessels detect the increase and send signals to the brain. The brain then stimulates the parasympathetic nervous system, which slows the heart rate and dilates blood vessels, leading to a decrease in blood pressure.

4.Calcium Homeostasis: When blood calcium levels rise, the thyroid gland releases calcitonin hormone, which promotes calcium deposition into bones and inhibits calcium reabsorption by the kidneys. This leads to a decrease in blood calcium levels.

5.pH Regulation: When blood pH becomes too acidic, chemoreceptors in the brain detect the change and stimulate the respiratory system to increase breathing rate. This expels more carbon dioxide from the body, reducing acidity and restoring normal pH levels.

1.Osmoregulation: When blood osmolarity (concentration of solutes) increases, osmoreceptors in the hypothalamus detect the change and stimulate the release of antidiuretic hormone (ADH) from the pituitary gland. ADH promotes water reabsorption by the kidneys, leading to a decrease in blood osmolarity.

2.Regulation of Red Blood Cell Production: When oxygen levels in the blood decrease (such as at high altitudes), the kidneys release erythropoietin hormone, which stimulates the bone marrow to produce more red blood cells. This increases oxygen-carrying capacity and helps restore normal oxygen levels.

3.Regulation of Hormone Secretion: Hormone secretion is often regulated by negative feedback loops. For example, as blood levels of a hormone increase, it inhibits further secretion of that hormone by the endocrine gland, helping to maintain hormone levels within a narrow range.

4.Regulation of Muscle Contraction: When a muscle contracts, calcium ions are released from the sarcoplasmic reticulum, leading to muscle contraction. As calcium levels decrease, the muscle relaxes, and calcium ions are pumped back into the sarcoplasmic reticulum.

5.Regulation of Blood Oxygen Levels: When blood oxygen levels decrease, chemoreceptors in the carotid and aortic bodies detect the change and stimulate increased breathing rate and depth. This increases oxygen intake and restores normal blood oxygen levels.

Excretion means the removal of waste products from cells.
There are five important excretory organs in humans:

- **Skin** excretes sweat, containing water, ions and urea
- **Lungs** excrete carbon dioxide and water
- **Liver** excretes bile, containing bile pigments, cholesterol and mineral ions
- **Gut** excretes mucosa cells, water and bile in faeces. (The bulk of faeces comprises plant fibre and bacterial cells, which have never been absorbed into the body, so are not excreted but egested.)
- **Kidneys** excrete urine, containing urea, mineral ions, water and other “foreign” chemicals from the blood.