HKU Med
LKS Faculty of Medicine
School of Clinical Medicine
香港大學臨床醫學學院

Concept of homeostasis of the body

BMSC1101/BMSN1601

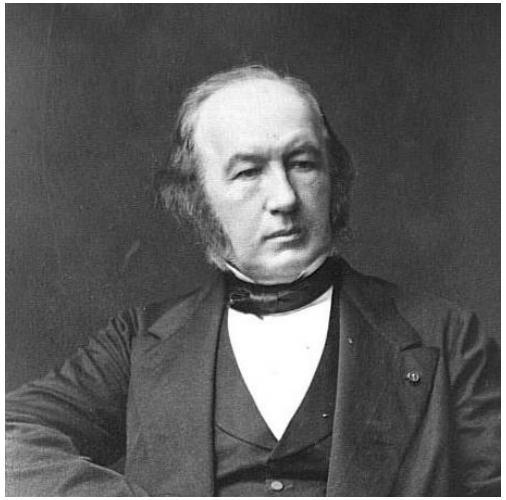
Dr Enoch Chan
Assistant Lecturer
School of Clinical Medicine

Learning outcomes

- Explain the concept of homeostasis and its importance in the maintenance of physical health.
- Explain how different organ systems interact to bring about physiological function and maintain homeostasis.
- Identify the functional components of a homeostatic control system: sensor, control centre and effector.
- Recognise the pattern of physiological functions, including negative feedback, feedforward and positive feedback.

Homeostasis

– The maintenance of a stable internal environment in the body.



Claude Bernard (1813 – 1878)

"The constancy of the internal environment is the condition for a free and independent life."

Walter Cannon (1871 – 1945)

Coined the term "homeostasis"

Homeostasis

The maintenance of a stable internal environment in the body.

– What is the ‘internal environment’?

– What do we mean by ‘stable’?

– How is the ‘maintenance’ achieved?

Homeostasis

The maintenance of a stable internal environment in the body.

- **What is the ‘internal environment’?**
- What do we mean by ‘stable’?
- How is the ‘maintenance’ achieved?

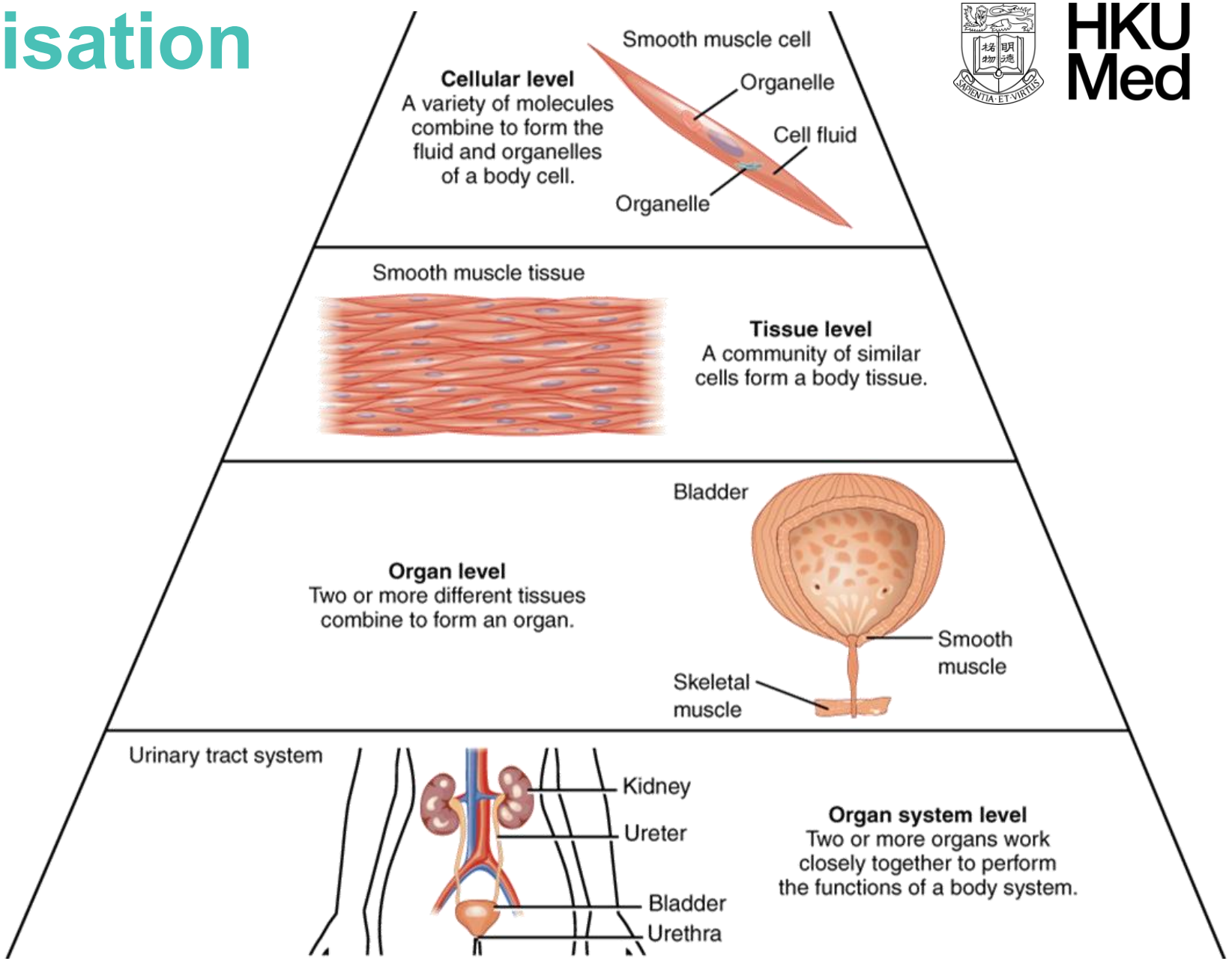
Levels of organisation

Cells

Tissues

Organs

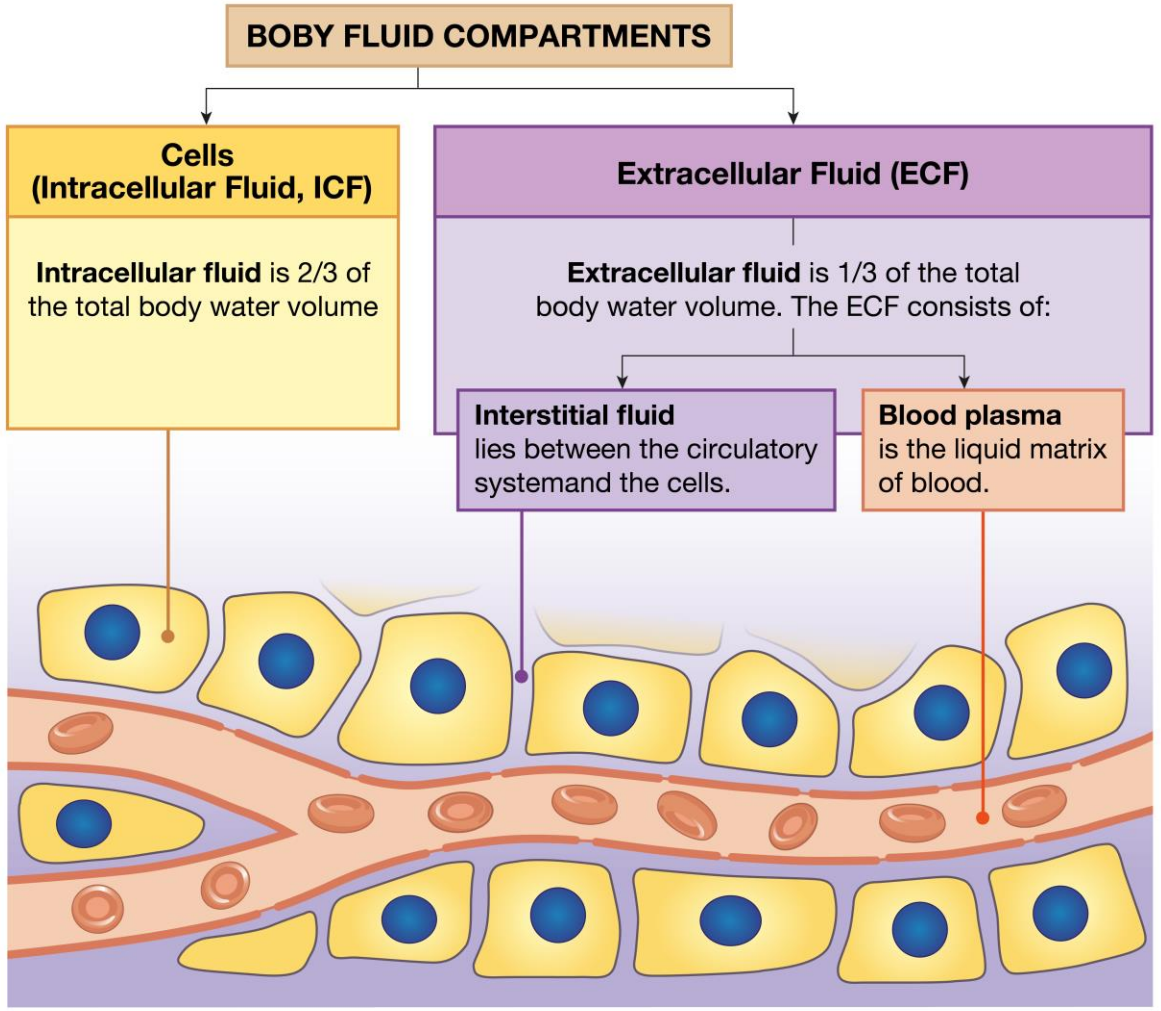
Organ systems



OpenStax College. (2022). Anatomy & Physiology. 2nd Ed. Figure 1.3

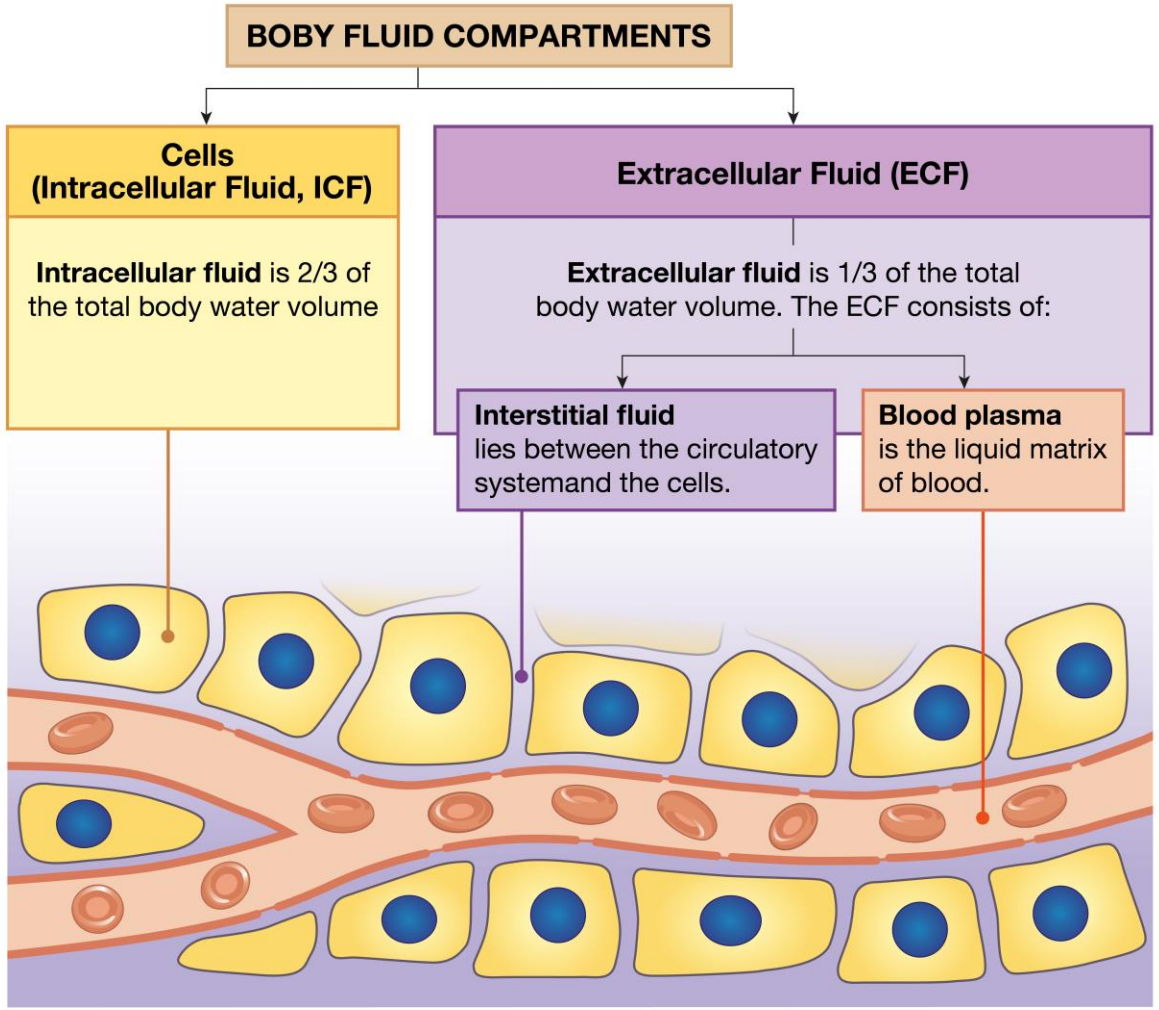
What constitutes “internal environment”?

- “Internal environment” is what surrounds each living cells in the body.
- Cells are surrounded by extracellular fluid (ECF) in the body:
  - Cells in most tissues are surrounded by *interstitial fluid*.
  - Blood cells in circulation (blood) are surrounded by *plasma*.
- “External environment” is what is outside the body.



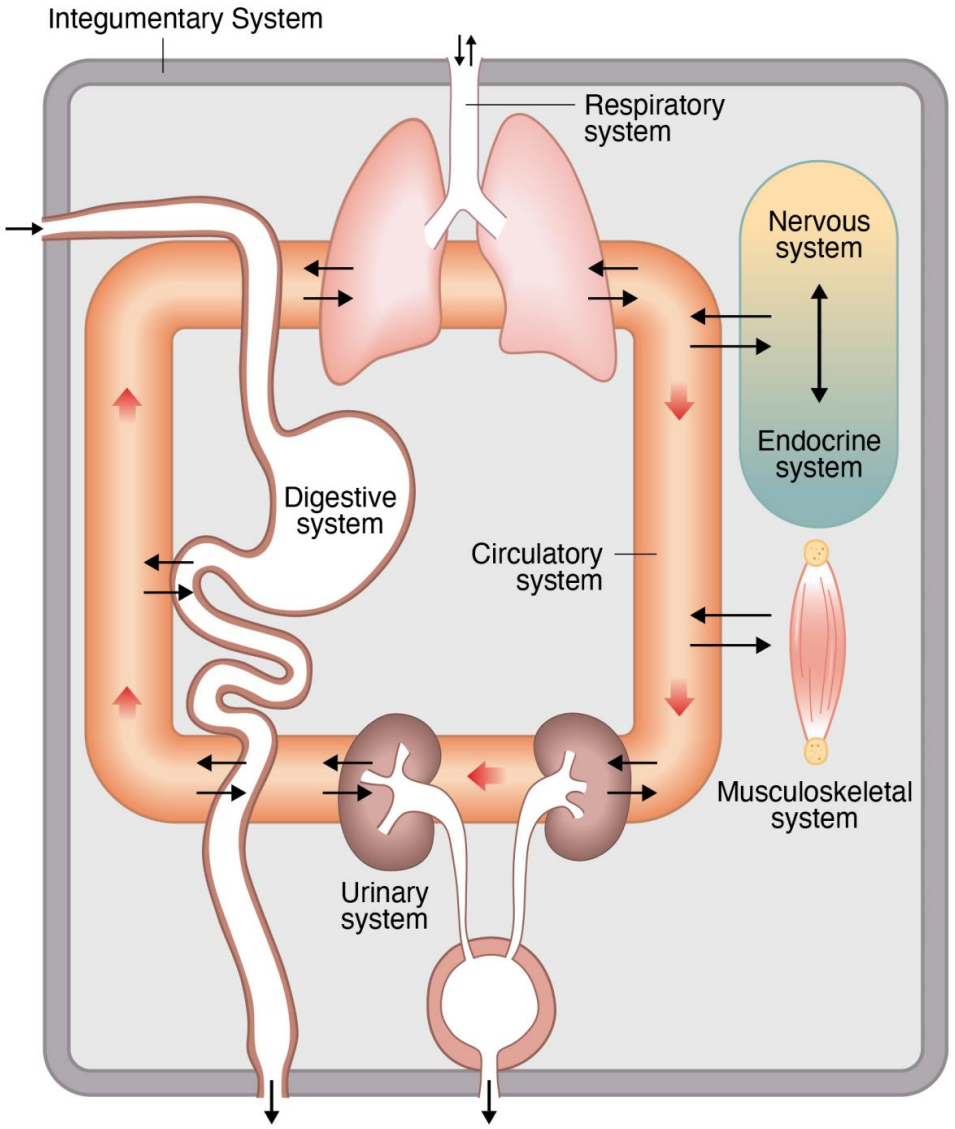
What constitutes “internal environment”?

- Water accounts for 50% to 70% of total body weight.
- Water is the solvent for various substances in the body (e.g. ions, nutrients, gases and more)
- Cells undergo most vital biochemical reactions in intracellular fluid (ICF).
- Cells also move substances between ICF and ECF.



Function of organ systems

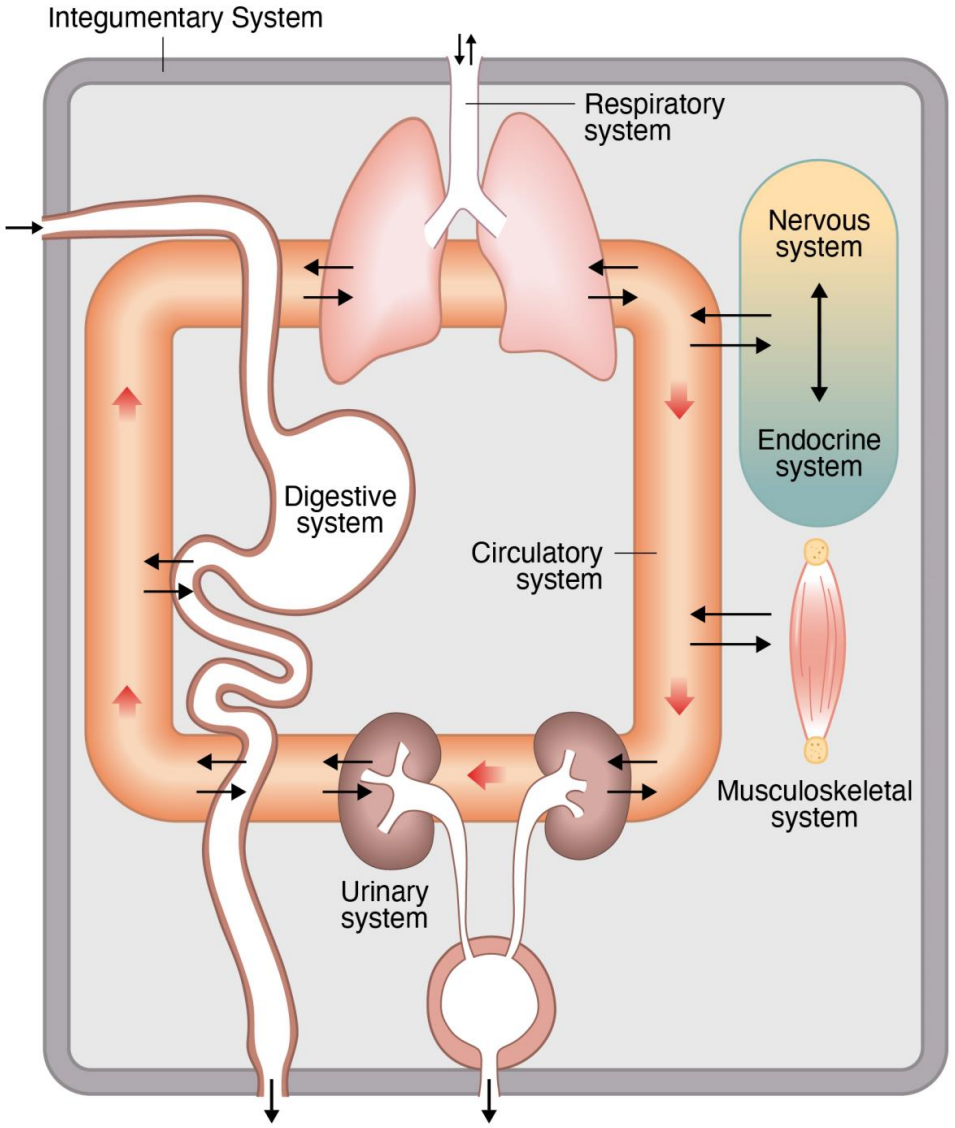
- **Nervous** and **endocrine systems** regulate body functions.
- **Integumentary system** forms a protective boundary around the body and regulates body temperature.
- **Musculoskeletal system** (muscular + skeletal) provides support and body movement; and produces blood cells (bone marrow)



Function of organ systems

- **Circulatory / Cardiovascular system** distributes materials by pumping blood through vessels.

- Systems exchanging materials between the internal and external environment:
  - **Respiratory system** (oxygen and carbon dioxide)
  - **Digestive system** (nutrients and water)
  - **Urinary system** (water and waste)



Organs and organ systems (1)

System	Major organs or tissues	Primary functions
Cardiovascular (Circulatory)	Heart, blood vessels, blood	Transport of blood, oxygen, nutrients and waste throughout the body
Digestive	Mouth, salivary glands, pharynx, oesophagus, stomach, intestines, pancreas, liver, gall bladder	Digestion and absorption of nutrients and water; elimination of waste
Endocrine	All glands or organs secreting hormones	Regulation of body functions such as growth, metabolism, reproduction, blood pressure, electrolyte balance and more
Immune	White blood cells, spleen, thymus, bone marrow, mucous membranes, lymph nodes, tonsils, skin	Defence against pathogenic microorganisms
Integumentary	Skin	Protection from injury and dehydration, regulation of body temperature
Lymphatic	Lymphatic vessels, lymph nodes	Transport of interstitial fluid from tissues into circulation

Organs and organ systems (2)

System	Major organs or tissues	Primary functions
Musculoskeletal	Cartilage, bone, ligaments, tendons, joints, skeletal muscle	Support, protection and movement of the body. Production of blood cells (bone marrow)
Nervous	Brain, spinal cord, peripheral nerves and ganglia, sense organs	Regulation and coordination of many activities in the body; detection of changes in the internal and external environment; state of consciousness; learning; cognition
Reproductive	Male: testes, penis and associated ducts and glands Female: ovaries, Fallopian tubes, uterus, vagina, mammary glands	Male: production and transfer of sperm Female: production of oocytes; maintaining optimal environment for embryonic / foetal development; nutrition for infants
Respiratory	Nose, pharynx, larynx, trachea, bronchi, lungs	Gaseous exchange; acid-base balance
Urinary	Kidneys, ureters, bladder, urethra	Regulation of plasma volume and composition; elimination of waste

Homeostasis

The maintenance of a stable internal environment in the body.

– What is the ‘internal environment’?

– **What do we mean by ‘stable’?**

– How is the ‘maintenance’ achieved?

Physical and chemical properties of the internal environment

Physical properties:

- Blood pressure
- Volume of ECF / blood
- Body core temperature

Chemical properties:

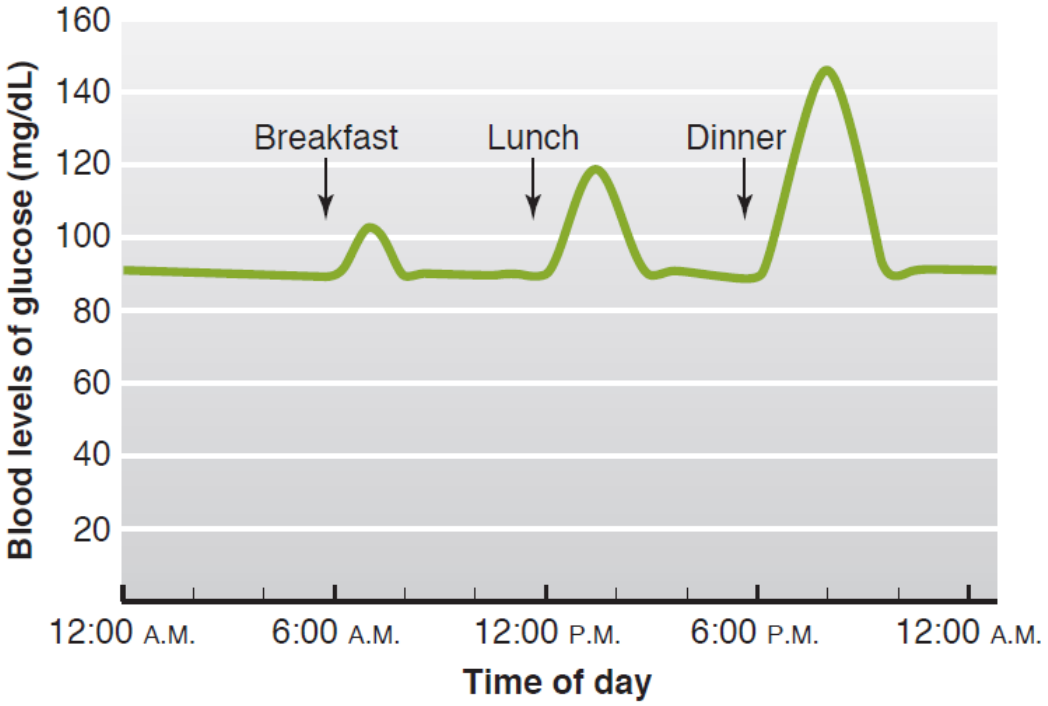
- ECF / blood concentration of ions (e.g. K^+, Ca^{2+}, Na^+)
- Blood pH level
- Blood glucose level
- Blood O_2 and CO_2 levels

Regulated variable

- In healthy mammals, most of the physical or chemical parameters tend to stay within a predictable range or at a ‘set point’.
- This is because they are regulated by multiple mechanisms in the body, hence they are also called ‘regulated variables’.
- For e.g. blood oxygen level of a healthy person would generally stay the same even under intense exercise, because of the regulation by the respiratory and cardiovascular systems.

Fluctuation of regulated variables

- Homeostasis is a state of dynamic constancy.
- Some variables do stay within a narrow range at all time.
- Some variables can change quite significantly throughout the day.
- When these variables become higher or lower than the normal range, the body acts to restore them to a “set point”.



Vander’s Human Physiology, Figure 1-3

Extracellular fluid parameters

Parameter	Normal range	Short-term non-lethal limit
Body temperature	36.1-37.2 °C	18.3-43.3 °C
Sodium ion	135-145 mmol/L	115-175 mmol/L
Potassium ion	3.5-5.3 mmol/L	1.5-9.0 mmol/L
Calcium ion	1.0-1.4 mmol/L	0.5-2.0 mmol/L
Bicarbonate ion	22-29 mmol/L	8-45 mmol/L
Acid-base (pH)	7.3-7.5	6.9-8.0
Oxygen	25-40 mmHg	10-1000 mmHg
Carbon dioxide	41-51 mmHg	5-80 mmHg
Glucose	70-115 mmol/L	20-1500 mmol/L

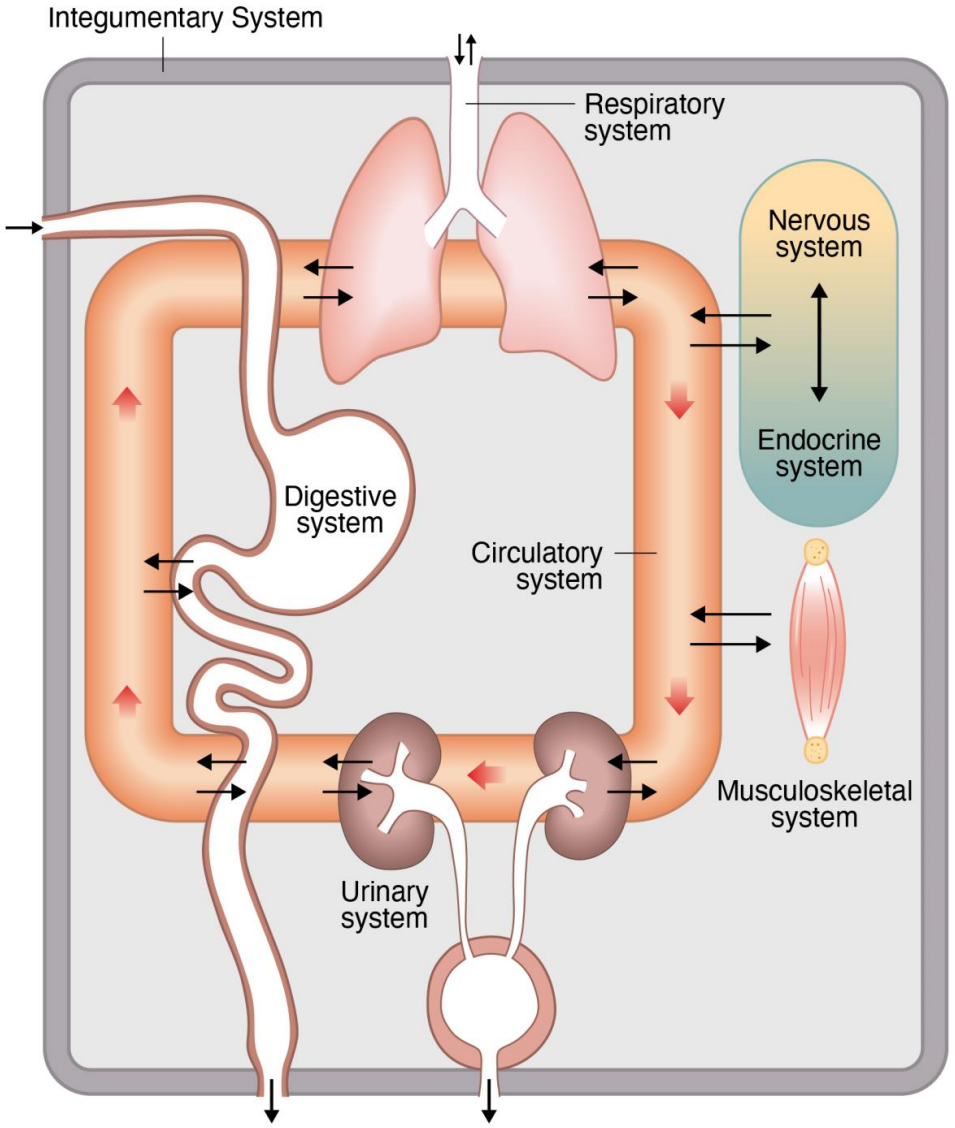
Guyton and Hall Textbook of Medical Physiology, Table 1-1

Homeostatic imbalance

- Sometimes the human body fail to maintain homeostasis, some parameters may deviate from their set points.
- Homeostatic imbalance may lead to disease states:
  - Diabetes (failure to regulate glucose level)
  - Hypertension or hypotension (failure to maintain normal blood pressure)

Interdependence of organ systems

- All organ systems are *interdependent.*
  - *e.g. our body requires the nervous and endocrine systems to function normally.*
  - *e.g. all living tissues rely on the cardiovascular system for the supply of oxygen and nutrients.*
- Some disease states involve failure of one or more organ systems.
- Failure of multiple organ systems can be lethal (lead to death).



Homeostasis

The maintenance of a stable internal environment in the body.

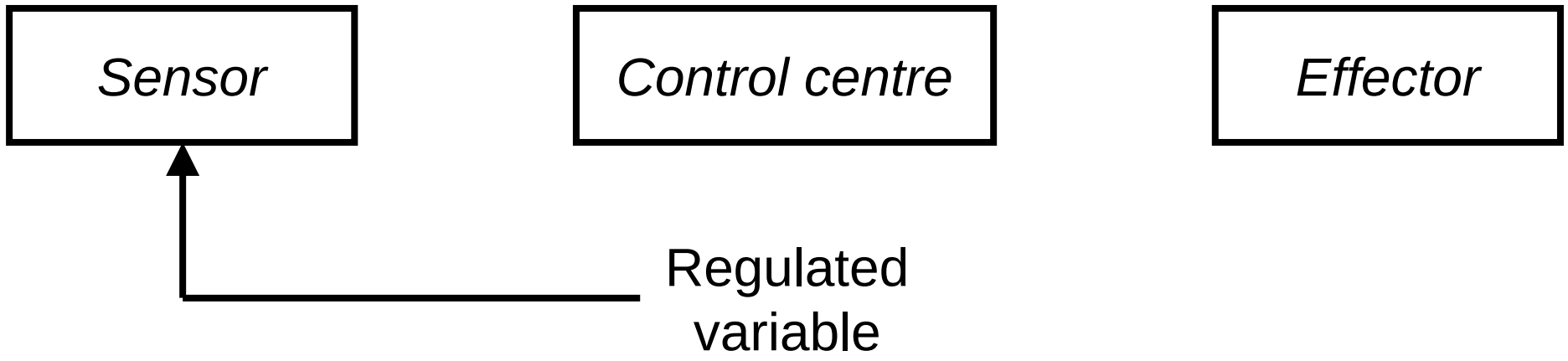
– What is the ‘internal environment’?

– What do we mean by ‘stable’?

– **How is the ‘maintenance’ achieved?**

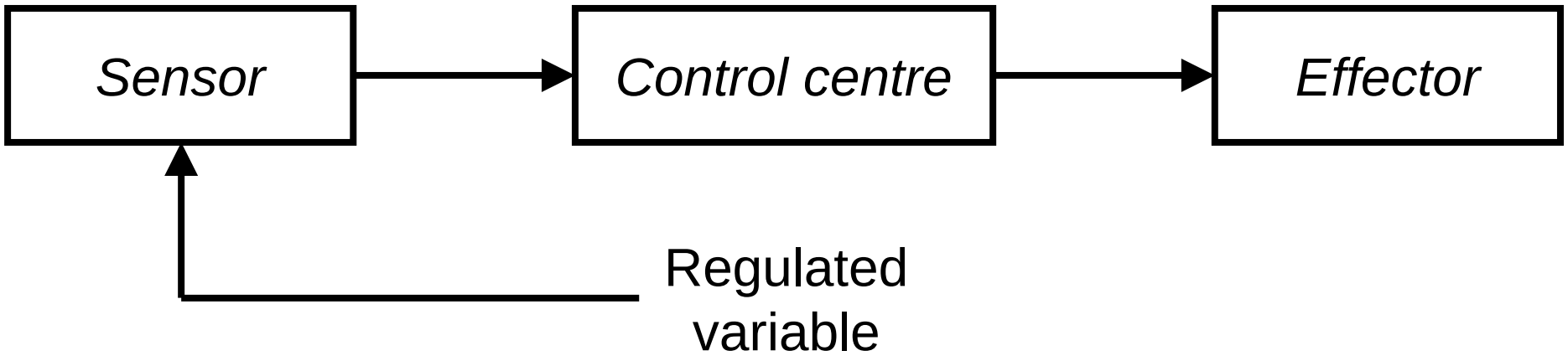
Homeostatic control system - sensors

- To maintain homeostasis, our body monitors these regulated variables using “sensors”.
- Examples of “sensors”:
  - sensory cells (thermoreceptor, baroreceptor, chemoreceptors, osmoreceptors)
  - cellular components (cell surface receptors or enzymes)



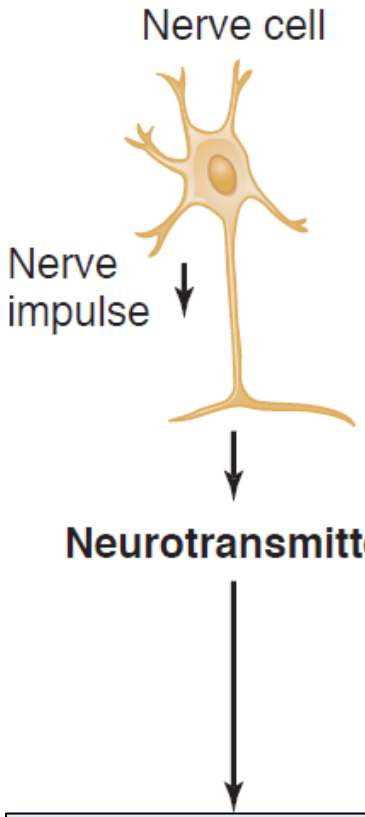
Homeostatic control system – control centre

- The “control centre” integrates signals from sensors and send output signal to the “effectors”.
- Control centres utilise electrical signals, chemical signals, or both to control the effectors and bring about changes in the regulated variable.
- Control centres are also called “integrating centre” in other texts.



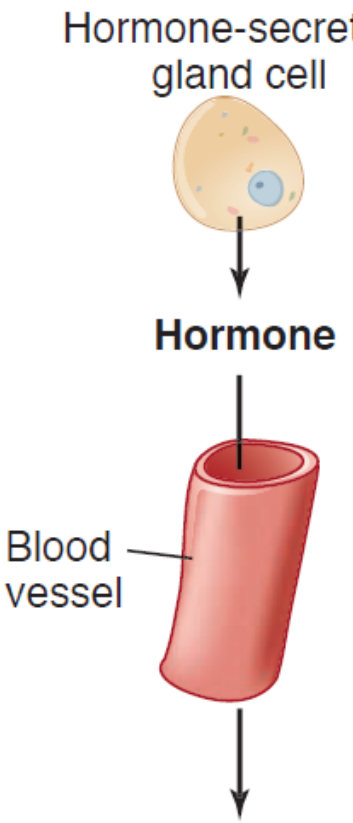
Chemical signals

Neurotransmitter



Neuron or effector cell in close proximity to site of neuro-transmitter release

Endocrine agent (hormone)

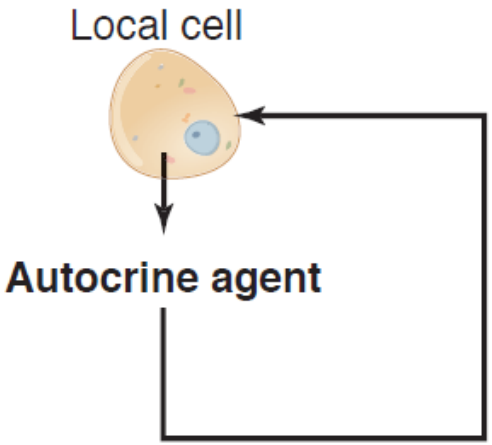


Target cells in one or more distant places in the body

Paracrine agent

Target cells in close proximity to site of release of paracrine agent

Autocrine agent

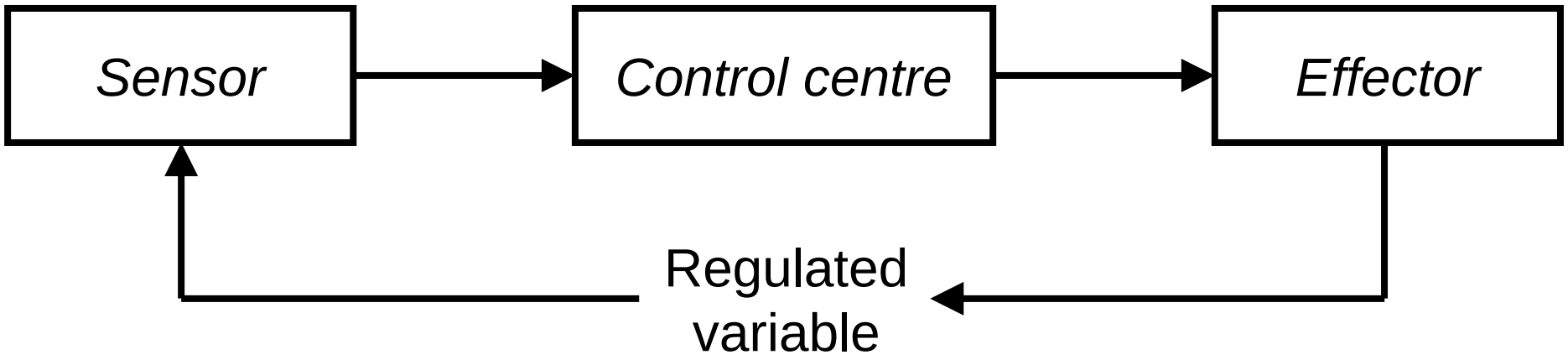


Autocrine agent acts on the same cell that secreted the agent

Vander's Human Physiology, Figure 1-8

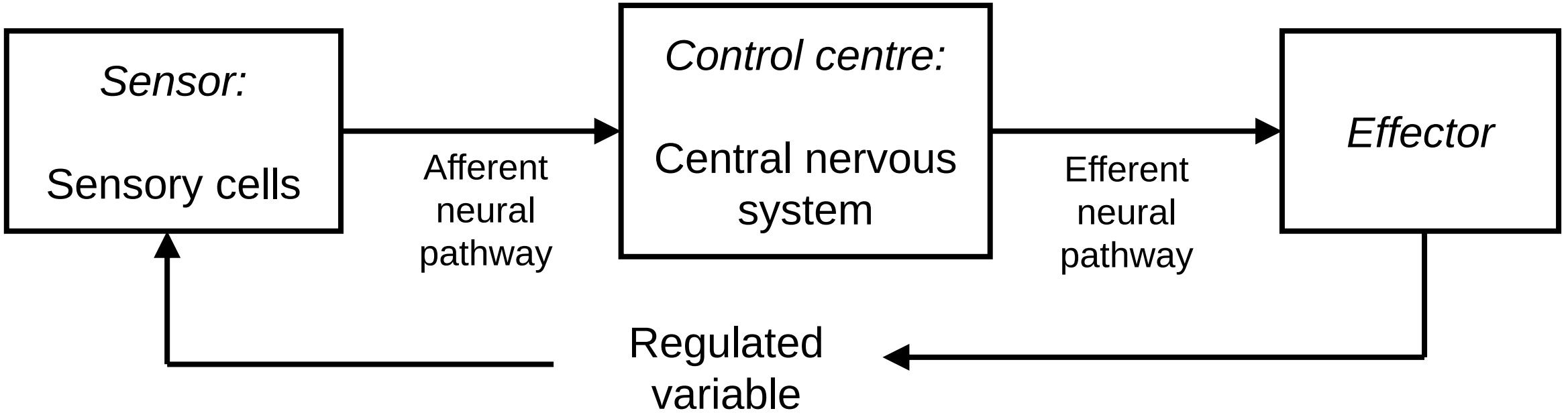
Homeostatic control system - effectors

- "Effectors" are the organs / tissues that determine the regulated variable.
- Examples of "effectors":
  - Blood glucose level: liver, adipose tissue, skeletal muscle
  - Blood volume and osmolarity: kidneys and blood vessels



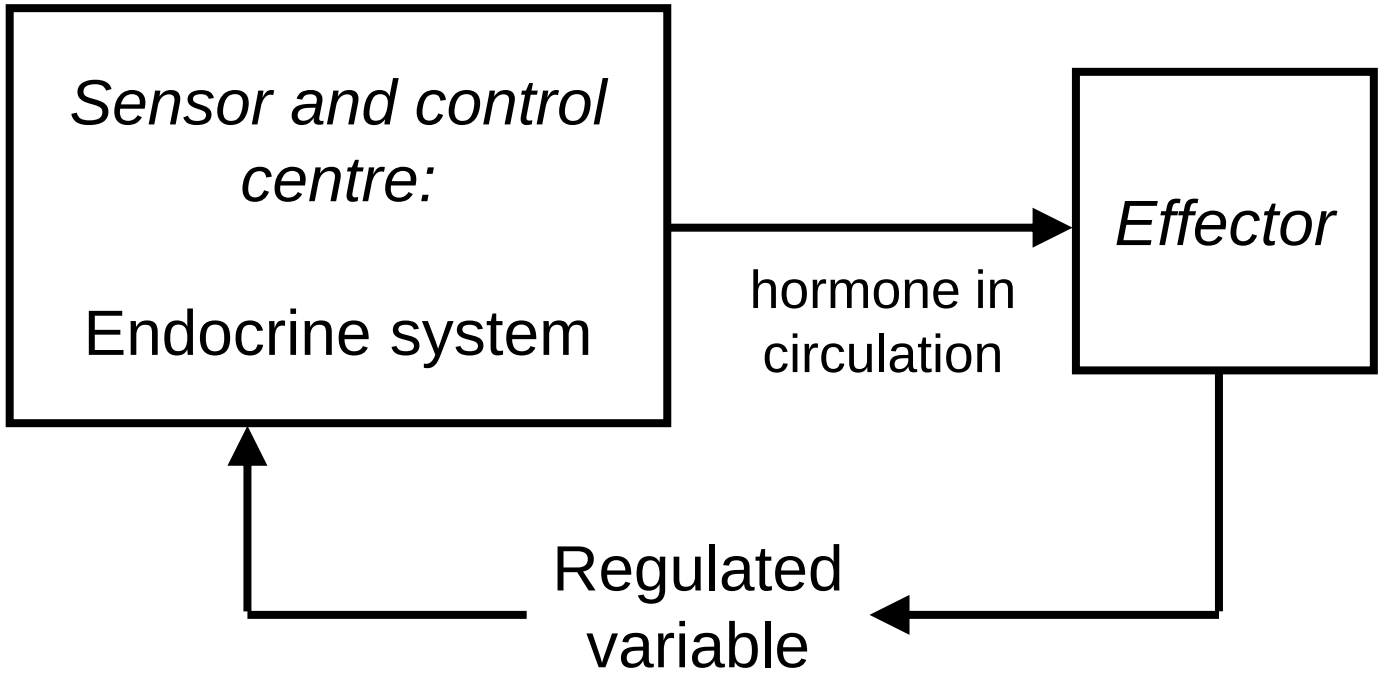
Neural mechanism

- Sensory cells send signal to the central nervous system via afferent neural pathway.
- Central nervous system send signal to effector via efferent neural pathway.
- Signals along afferent and efferent neural pathways are in the form of neurotransmitters and electrical signal (action potentials).



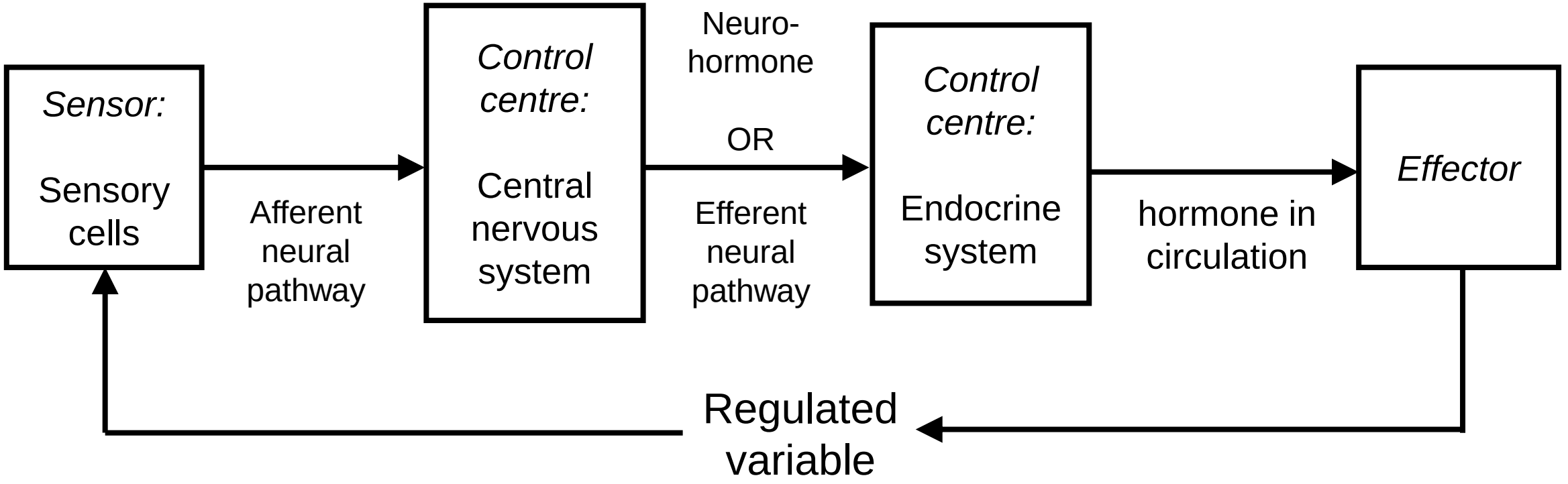
Endocrine mechanism

- Endocrine gland can act as both sensor and control centre.
- Changes in regulated variable would directly stimulate endocrine glands to secrete hormones into the circulation.
- Hormones would circulate around the body until they reach the cells / tissues they can target.



Neuroendocrine mechanism

– Endocrine gland can also receive signal from central nervous system via neurohormone or efferent neural pathway.



Properties of control mechanisms

Property	Neural mechanism	Endocrine / Neuroendocrine mechanisms
Speed	Immediate response	Slower than neural
Specificity	Localised effects	Global effect
Duration of action	Usually very short	Last longer than neural

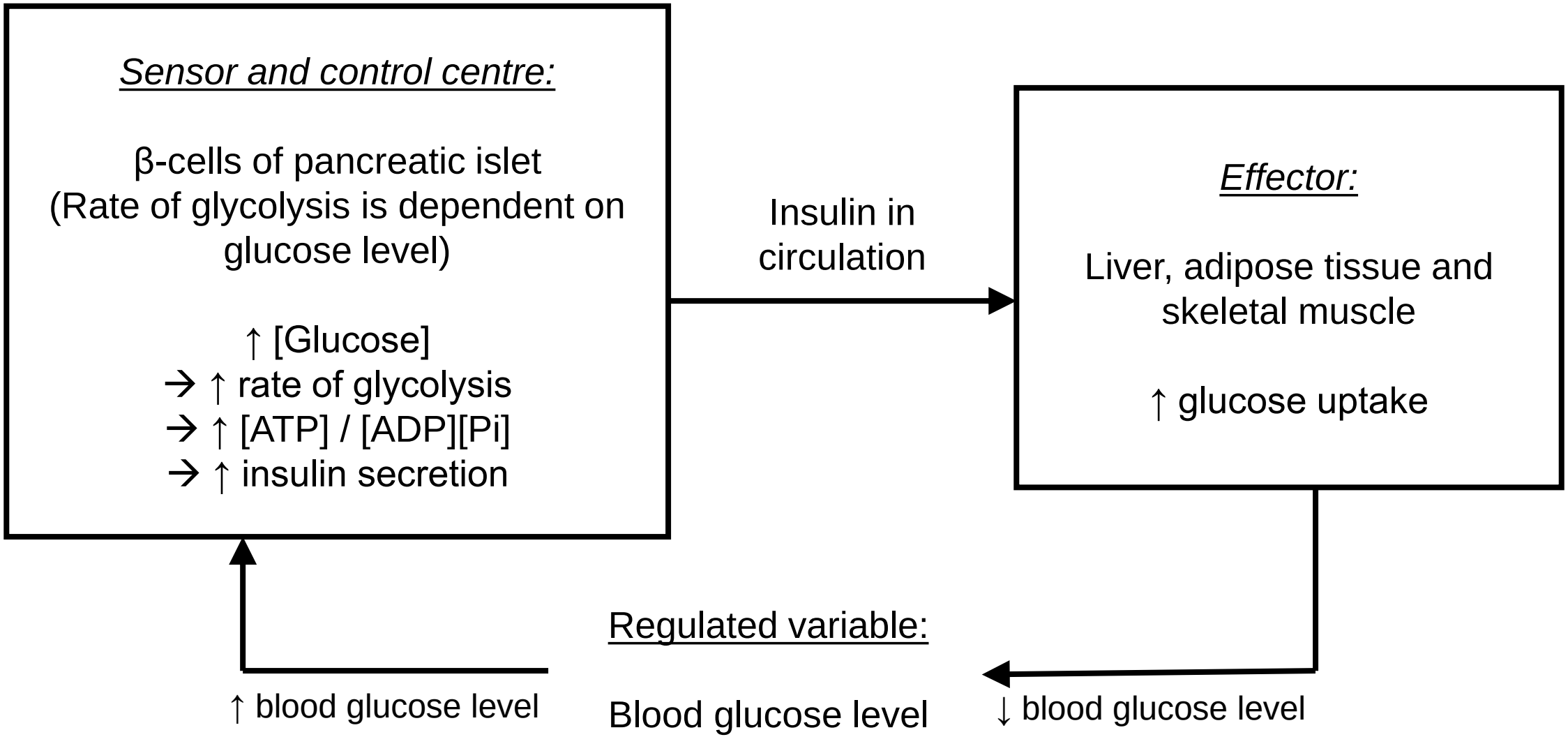
Regulation of blood pressure

Baroreceptors are activated when blood pressure rises. This causes them to fire action potentials more frequently along the afferent neural pathway to the medulla oblongata.

The medulla oblongata reduces the amount of action potentials sent via sympathetic nerve, while promoting action potentials sent via parasympathetic nerve.

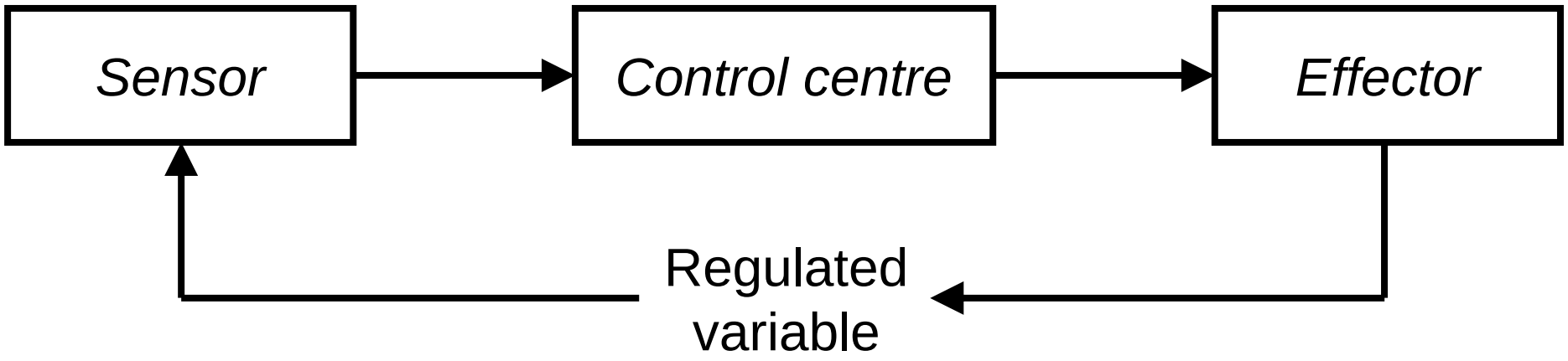
These together cause the heart to beat slower and contract with less force, decreasing blood pressure.

Regulation of blood glucose (fed state)



Negative feedback loop

- For most physiological variables, homeostasis is driven by negative feedback loop.
- Changes in regulated variables are detected by the sensor.
- The effector acts to change the regulated variable towards normal levels, and this eliminates the stimulus detected by the sensor.
- Negative feedback loop reduces the variability of a regulated variable.



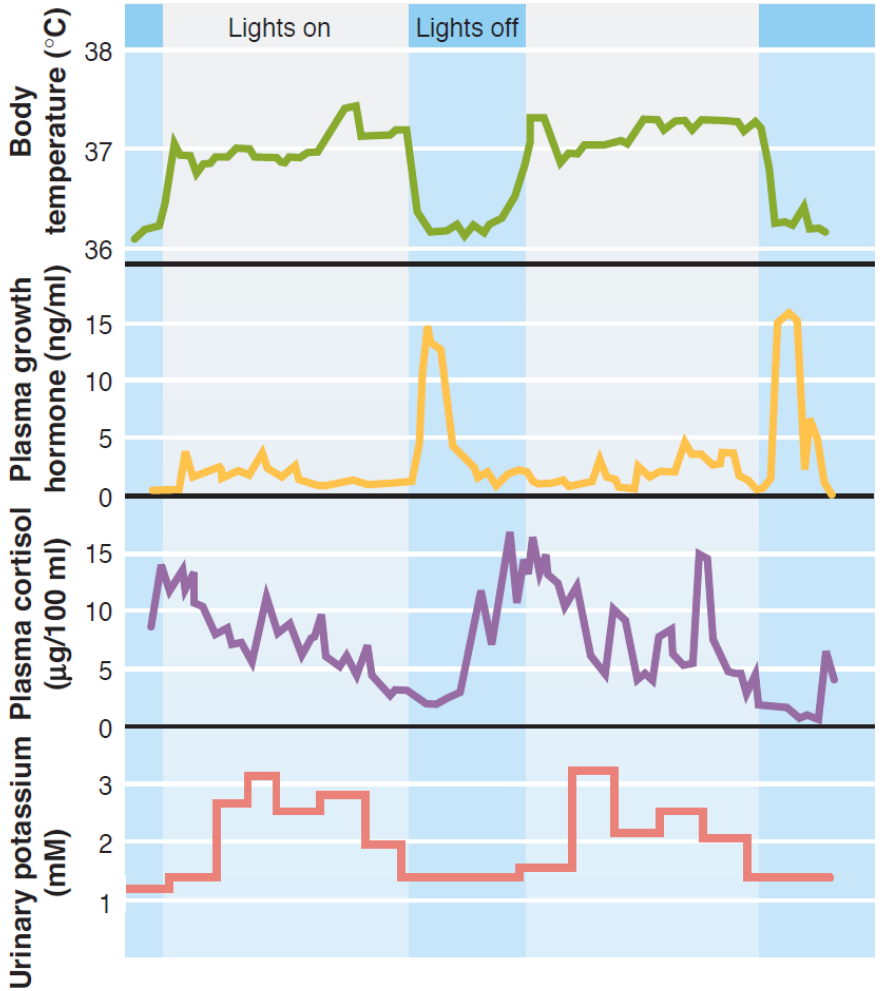
Additional processes that influence homeostasis

- Circadian rhythm

- Feedforward control

Circadian variation of physiological parameters

- Some physiological variables changes according to circadian rhythm, including but not limited to:
  - Body temperature
  - Concentrations of growth hormone and cortisol in blood
  - Urinary excretion of ions
- Circadian rhythm follows a 24h light-dark cycle:
  - Central nervous system receives input from eyes and in response, influence various organ systems.



Vander's Human Physiology, Figure 1-9

Feedforward control (anticipatory response)

- While negative feedback loops can stabilise the internal environment, but they are unable to prevent changes from happening in the first place.
- The human body also employs feedforward control mechanisms to make adjustments *before* the changes happen.
- Example:
  - when a person is about to begin exercising, their heart rate will increase before moving commences.

Positive feedback

- Not all physiological functions are regulated by negative feedback loop.
- Some non-homeostatic physiological functions are driven by positive feedback loops.
- Unlike negative feedback (which eliminates the input signal), positive feedback loops *amplify* the input signal.
  - Positive feedback loops can bring about an effect very quickly (amplification of the input signal accelerates the process)
  - Additional mechanisms in place to turn off the positive feedback loops.
- Examples:
  - Coagulation cascade
  - Childbirth
  - Surge of luteinising hormone after follicular phase of menstrual cycle

Summary

- Explain the concept of homeostasis and its importance in the maintenance of physical health.
  - Homeostasis is about maintaining stable physical / chemical properties of internal environment (extracellular fluid).
  - Homeostatic control systems (sensor, control centre and effector) maintain regulated variable within predictable range.
  - Mechanism of control: neural, endocrine and neuroendocrine
  - Essential for survival and good health.
  - Some abnormalities in physiological variables are tolerated short-term, but are harmful / lethal in long run.

Summary

- Explain how different organ systems interact to bring about physiological function and maintain homeostasis.
  - Various organ systems: cardiovascular, digestive, endocrine, immune, integumentary, lymphatic, musculoskeletal, nervous, reproductive, respiratory and urinary.

- Identify the functional components of a homeostatic control system: sensor, control centre and effector.
  - Sensory cells or component of a cell act as sensor
  - Nervous system and/or endocrine system act as control centre(s)

Summary

- Recognise the pattern of physiological functions, including negative feedback, feedforward and positive feedback.
  - Most homeostatic control systems are negative feedback loops, but some non-homeostatic functions are driven by positive feedback loops.
  - Negative feedback loops are self-limited: they eliminate the input signal (deviation of regulated variables from setpoints).
  - Positive feedback loops amplify the input signal → a quick effect.
  - Circadian rhythm and feedforward control also influence homeostasis.

References

Silverthorn, *Human Physiology*, 8th edition

– Ch 1, 6

Vander's Human Physiology, 13th edition

– Ch 1

HKU Med

LKS Faculty of Medicine
The University of Hong Kong
香港大學李嘉誠醫學院