

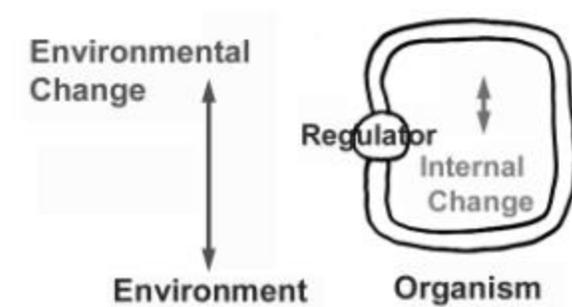
## PHYSIOLOGY & HOMEOSTASIS

(Chpt 40)

- All living organisms, from cells upward, are in disequilibrium with their environment.
- In your body, for example, the extracellular fluid (blood, lymph) is of different composition than the cytoplasm and different in turn from the air or water.
- Within the organism, and within individual cells, however, the *milieu internal*, the internal medium, has to be maintained within strict limits.

### General Principles of Homeostasis

- **Homeostasis** refers to the capacity of living things to maintain their **internal composition constant** despite changes in the external environment.



## General Principles of Homeostasis

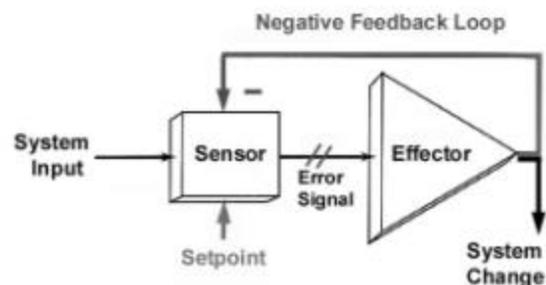
- In order to maintain homeostasis, systems must be controlled and regulated.
- **Control** refers to the organism or system's capacity to change the rate of a reaction or process.
- **Regulation** refers to the capacity to maintain a variable within specific limits.

## Setpoints and Feedback

- If we consider the model of a thermostat, some of the basic principles of homeostasis can be demonstrated.
- A feedback loop consists of a sensor, which has a **setpoint**, an effector (or control mechanism), which can put in a correction, and a linkage between the two.
- The **setpoint** refers to the level (concentration, temperature, etc.) at which the system is set.

- In your house, the thermostat acts as a sensor, and the **setpoint** is the temperature that you set to turn on the furnace (or A/C).
- When the temperature drops (or rises) beyond the **setpoint**, an **error signal** is received by the sensor.
- Electrical contacts are closed and a signal is sent to the furnace (the effector) which pumps heat into the house until the temperature rises above the **setpoint**, canceling the **error signal**, and the system shuts down.
- This is an example of **negative feedback**.

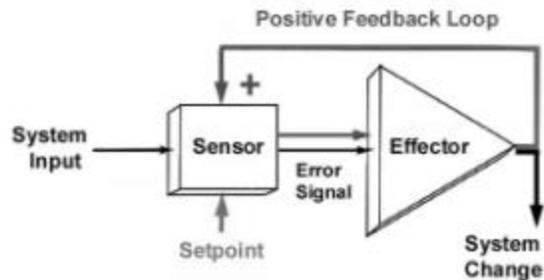
## Negative Feedback



Effector output **inhibits** the sensor signal.

- Typically, biological sensor systems have an upper and lower setpoint bracketing the acceptable range of physiological values. The effector will depend on which setpoint is activated.

## Positive Feedback



Effector output **stimulates** the sensor signal.

- **Negative feedback** is important in self-regulating systems, but many biological systems (e.g. nerve action potentials, hormone cascades) also rely on **positive feedback**.

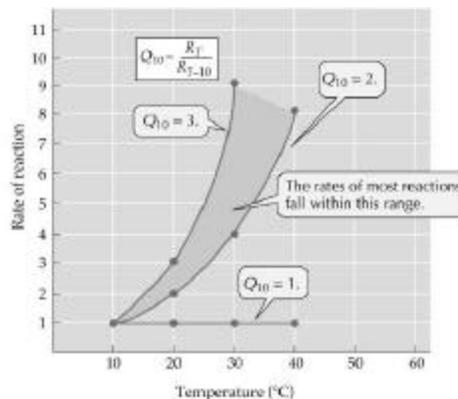
- The final component of **regulatory systems** is **feedforward**.
- this is information that doesn't immediately apply to the system, but is used to regulate the **setpoint**.
- examples would be the internal clocks that determine when to lay down fat for the winter, when to conceive or when to migrate.
- **feedforward** is particularly important in behavior.
- in a complex organism, there are many, many feedback loops. Just in your circulatory system, there are feedback loops for temperature, pH, CO<sub>2</sub>, O<sub>2</sub>, glucose, albumin, red cell numbers, white cell numbers, etc., etc.

## EFFECTS OF TEMPERATURE

- biochemical reactions, and therefore biological systems, are very sensitive to changes in temperature.
- this effect is the **temperature quotient**, or  $Q_{10}$ , which is considered to be the **reaction rate** at a given temperature ( $R_T$ ) divided by the rate 10°C lower ( $R_{T-10}$ ), so:

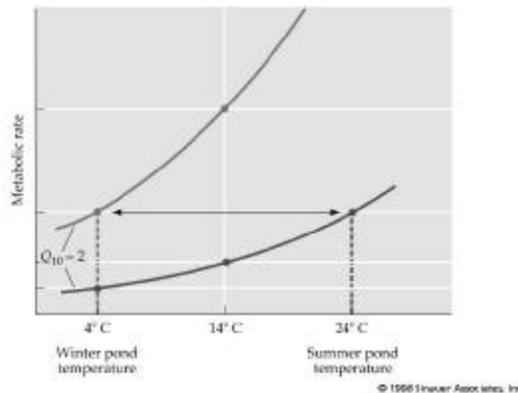
$$Q_{10} = R_T / R_{T-10}$$

A reaction that is **not** temperature-sensitive would have a  $Q_{10} = 1$ . In general, biological systems have a  $Q_{10} = 2$  or 3, that is, the reaction rate doubles or triples with every 10°C rise in temperature. (**Fig. 40.6**)



© 1998 Sinauer Associates, Inc.

- Animals are slowly able to compensate for the effects of  $Q_{10}$  in a process known as **acclimatization**.
- for example, fish sampled in winter and summer both demonstrate a  $Q_{10}$  of 2, but their rates of basal metabolism are nearly identical. (Fig. 40.7)



In a process known as **metabolic compensation**, organisms are able to synthesize different forms of enzymes (called **allozymes**), which have different temperature optima. Replacing enzymes is a slow process, so **acclimatization** usually takes place over a period of weeks

## Maintaining Optimal Body Temperature

- Animals have taken three basic strategies towards temperature regulation.

**Homeotherms** regulate their body temperature at a constant level

**Poikilotherms** allow their body temperature to fluctuate with the environment.

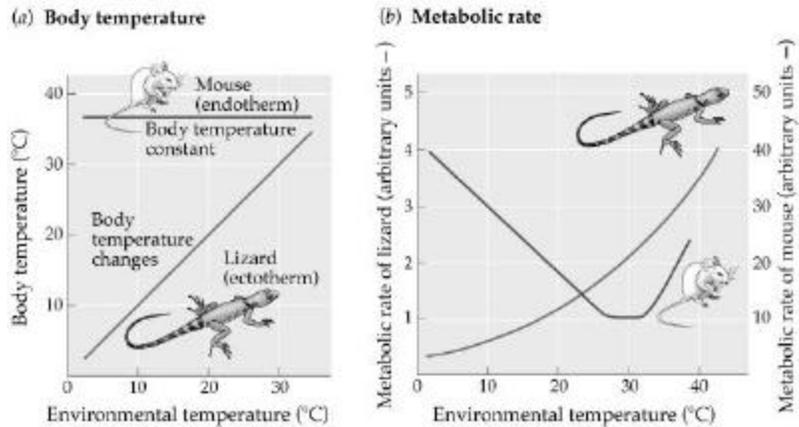
**Heterotherms** regulate their temperature some of the time.

**Endotherms** (warm-blooded animals) can use their internal resources to regulate temperature.

**Ectotherms** are totally reliant on external sources of heat.

- So a mammal with a body temperature of 37°C, and a deep-sea fish living in water at a constant 4°C may both be considered **homeotherms**, but the fish is an **ectotherm** and the mammal is an **endotherm**.

## ECTOTHERMS vs ENDOTHERMS (Fig. 40.8)



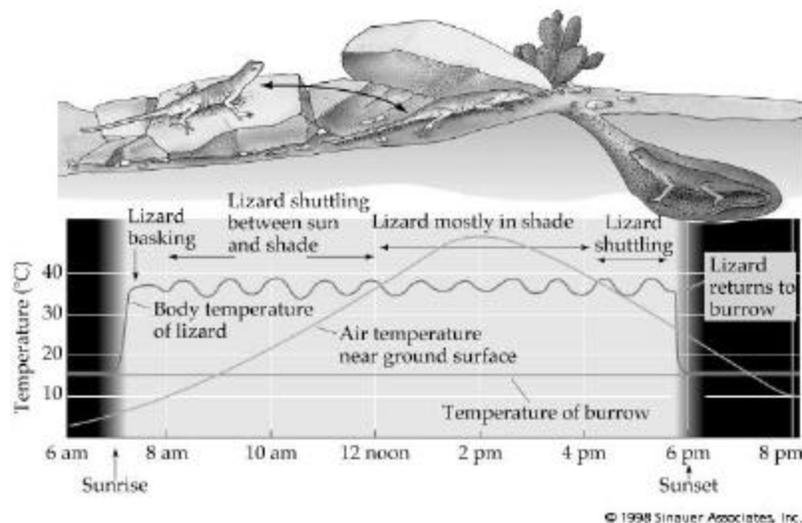
© 1998 Sinauer Associates, Inc.

### Ectotherms Can Regulate Temperature Behaviorally and Physiologically

- Being **ectothermic** (or “cold-blooded”), does not necessarily mean that animals cannot control their body temperature.
- An ectothermic lizard, living in the desert, where the air temperatures can vary by 40°C over the course of a day, actually has a very stable body temperature, which it regulates behaviorally.
- During its inactive periods, the lizard remains in its burrow, which is at a constant temperature of 10°C to 15°C, conserving energy at this lower temperature.

- During the day, when the lizard must be active and alert, both to hunt for food and avoid predators, it alternates between sunlight and shade to maintain its body temperature in the 35°C to 40°C range.
- With a  $Q_{10}$  of 2, this would mean that the lizard's metabolic rate will be 4 times as great during the day, making it as agile as any endotherm.

## Behavioral Regulation of Temperature (Fig. 40.9)



## Physiological Thermoregulation

In addition to behavioral mechanisms, ectotherms use several metabolic processes to aid in thermoregulation

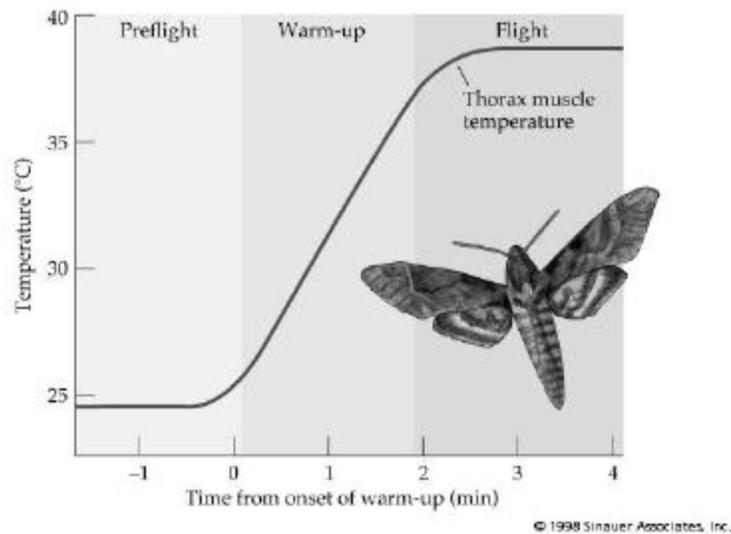
### 1) Control of Blood Flow to the Skin

Ectotherms can influence the rate of heat exchange with their environment by altering the blood flow to the skin. To warm up, a lizard shunts large volumes of blood to the skin for maximum absorption of heat. For the marine iguana, which must go from sun-baked rocks at 40+°C into the ocean at 7°C, shunting blood flow means it can conserve heat in the water and increase its temperature quickly when back on land.

### 2) Metabolic Heat Production

- Many ectotherms are unable to function below a certain temperature. Moths and dragonflies, for example, must have a thoracic temperature of 35°C to 40°C in order to fly.
- By using their powerful flight muscles to contract isometrically (opposing muscles contract at the same time, so no net work is done, but heat is produced from ATP hydrolysis) they are able to generate enough heat so they can fly.
- This is called **shivering thermogenesis**. These insects control blood flow to the abdomen, using it as a radiator to prevent thoracic temperatures from exceeding 45°C.

### Metabolic Heat Production (Fig. 40.13)



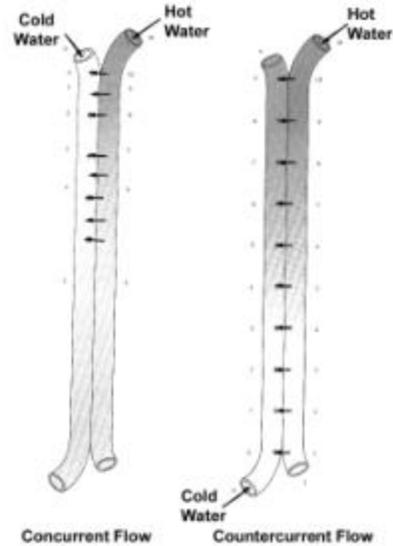
### 3) Biological Heat Exchangers

- Many animals, particularly in cold environments, cannot supply sufficient metabolic heat to maintain the entire body at elevated temperatures. Heat is retained in specific regions by means of a special network of blood vessels called the *rete mirabile*.
- The rete acts as a **countercurrent heat exchanger**.
- Countercurrent mechanisms function in many areas ( $O_2$  uptake in fish gills, kidneys, etc.), but they are most noticeable in heat exchange.

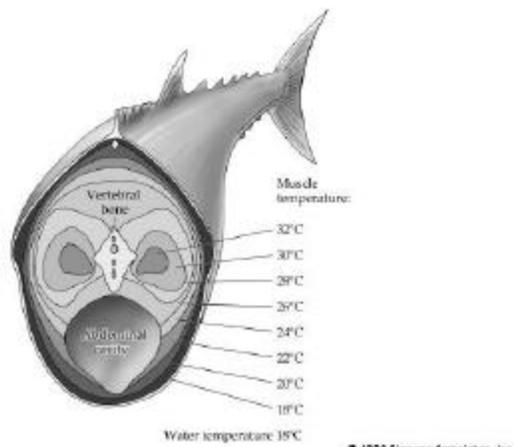
## Concurrent vs Countercurrent Flow

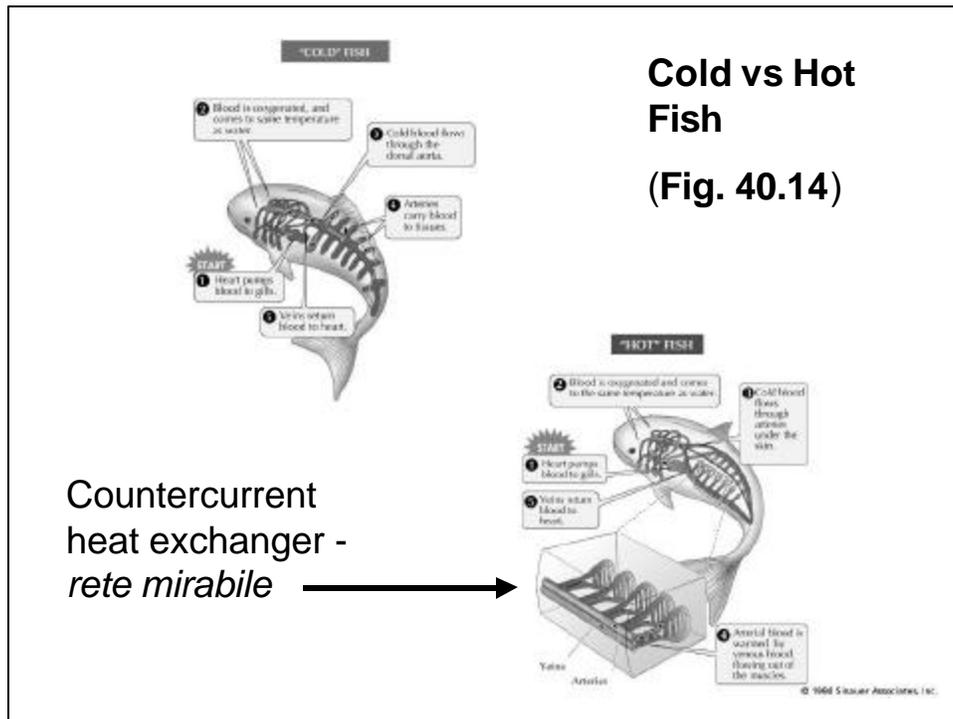
When fluid moves in the same direction (**concurrent**), both end up at the same concentration.

When fluid moves in opposite directions (**countercurrent**), concentration differences are established at either end.



An example would be a “hot” fish, like the tuna. Red (i.e. aerobic) swimming muscle has a  $Q_{10}$  of 3, so every  $10^{\circ}\text{C}$  increase in muscle temperature increases available power output by 3-fold.





## Thermoregulation in Endotherms

- **Endotherms** are capable of responding to changes in environmental temperature by altering their metabolic rate.
- Within a narrow temperature, called the **thermoneutral zone**, the metabolic rate is low and does not shift in response to temperature.
  - The metabolic rate of a resting animal in its thermoneutral zone is called the **basal metabolic rate (BMR)**.
- Endothermy is metabolically expensive. The BMR of an endotherm is typically 6 times that of a similar size ectotherm at the same body temperature.

## Active Heat Production and Loss

- Endotherms employ all the thermoregulatory mechanisms used by ectotherms: behavior, blood flow regulation, metabolic heat production and retes (heat exchangers).
- There are also a number of passive mechanisms for reducing heat loss; fur or feathers instead of bare skin, and the presence of layers of subcutaneous fat.
- The thermoneutral zone is bounded by an upper and lower **critical temperature**.
- As the environmental temperature drops below the critical, the endotherm responds by increasing its metabolic rate (MR).

At some point the animal reaches its summit metabolism, or maximum rate of metabolic heat production. If the environmental temperature continues to drop, the lower lethal temperature is reached and the animal dies

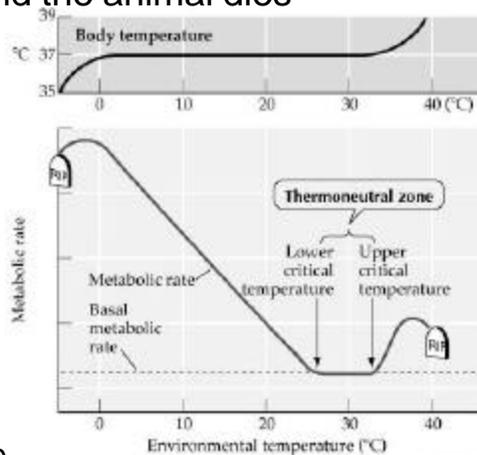


Fig.  
40.15

Fig.  
37.19

- In addition to being able to produce heat by shivering, most endotherms possess specialized heat-generating tissue called **brown fat**.
- In response to activation by the protein **thermogenin**, brown fat is capable of directly burning ATP to produce heat.
- Above the upper critical temperature the animal expends energy cooling, but at some upper lethal temperature these mechanisms are inadequate and the animal dies.
- **Evaporative water loss**, such as panting or sweating, is very effective for cooling (remember it takes 540 cal/g to convert liquid H<sub>2</sub>O into vapor).

- Survival in hot environments, therefore, usually means having access to adequate supplies of water.
- The upper lethal temperature is usually much more sharply defined than the lower.

## THE VERTEBRATE THERMOSTAT

- The vertebrate thermostat is located in the part of the brain called the **hypothalamus**.
- This can be demonstrated using endotherms (actually heterotherms) such as ground squirrels, that can tolerate large shifts in core temperature during bouts of **hibernation**.
- Manipulation of hypothalamic temperature produced large shifts in MR, with corresponding changes in core temperature, independent of the environmental temperature

