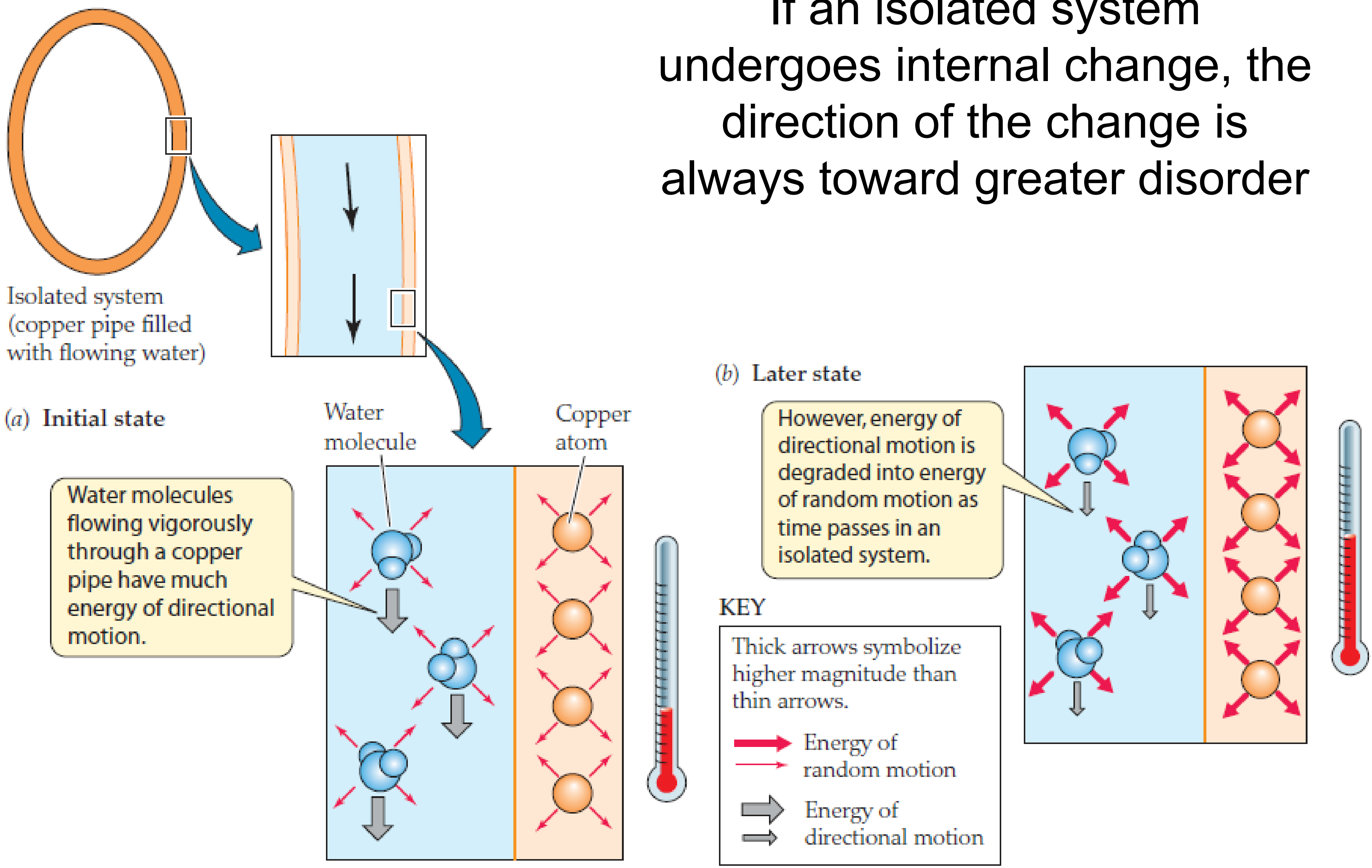
# 6. Thermoregulation in poikilotherms and homotherms

BIOS 0501B (Group A)

DBS, PU, Sem 5; 2015

# Thermodynamics

If an isolated system undergoes internal change, the direction of the change is always toward greater disorder



# Energies

- High grade Energies
  - Chemical energy (directly or indirectly):
    - All forms of physiological work [totipotent = *toti*, “all”; *potent*, “powerful”]
  - Electrical and mechanical energy
    - Accomplish some forms of physiological work, but neither form of energy is totipotent
- Low grade energies
  - Heat
    - Waste, cells can not use this energy. So they release it

# Energy efficiency

$$\text{Efficiency of energy transformation} = \frac{\text{output of high-grade energy}}{\text{input of high-grade energy}}$$

- 70% of the energy released from glucose is incorporated into bonds of ATP - high-grade energy
- The other 30% - which started as high-grade energy - becomes low-grade energy: heat
- Muscle cell uses 25%–30% of ATP energy to contract
- Rest is heat
  - We waste a lot. A very inefficient system

# Why do animals need energy?

- *Biosynthesis*. An animal synthesizes its body constituents, such as its proteins and lipids, by use of absorbed energy.
- *Maintenance*. An animal's maintenance functions are all the processes that *maintain the integrity* of its body; examples include circulation, respiration, nervous coordination, gut motility, and tissue repair. With only trivial exceptions, *the energy used for maintenance is degraded entirely to heat within the body*.
- *Generation of external work*. Animals perform external work when they apply mechanical forces to objects outside their bodies.

# Metabolic rate

- An animal's metabolic rate is one of the most important determinants of *how much food it needs*. For an adult, food needs depend almost entirely on metabolic rate.
- Because every energy-using process that takes place in an animal produces heat, an animal's metabolic rate—its *total* rate of heat production—provides a *quantitative measure of the total activity of all its physiological mechanisms*. An animal's metabolic rate, roughly speaking, represents the animal's *intensity* of living.
- Ecologically, an animal's metabolic rate measures the *drain the animal places on the physiologically useful energy supplies of its ecosystem*, because the metabolic rate is the pace at which the animal degrades the chemical energy of organic compounds in its ecosystem.

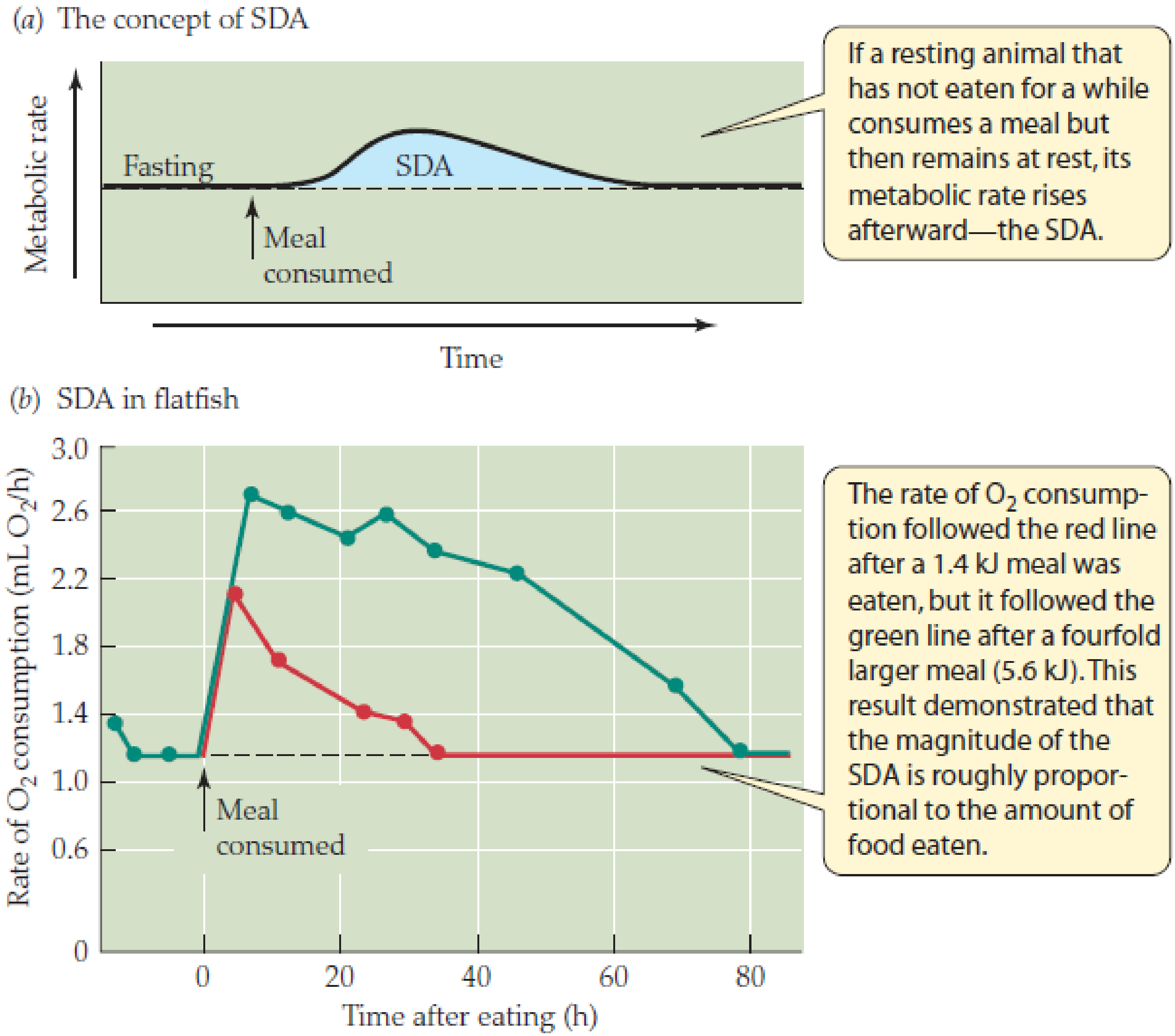
# Measuring metabolic rate

- Directly: calorimeter - a device that measures the rate at which heat leaves an animal's body
  - Hard to keep an animal in conditions suitable for measurements
- Indirectly: measuring oxygen - rate of oxygen consumption if proportional to its metabolic rate
  - Hard to keep track of the materials being used to oxidized
- Indirectly: measuring carbon di oxide - rate of $CO_2$ release if proportional to its metabolic rate
  - Ambiguity as above
- The ration of $O_2$ & $CO_2$ is not a great tactic either

# Factors affecting metabolic rate

Ingestion of food

- Under many circumstances, if an animal has not eaten for a while and then consumes food, its metabolic rate temporarily increases following the meal *even though all other conditions are kept constant*.
  – specific dynamic action (SDA)



# And

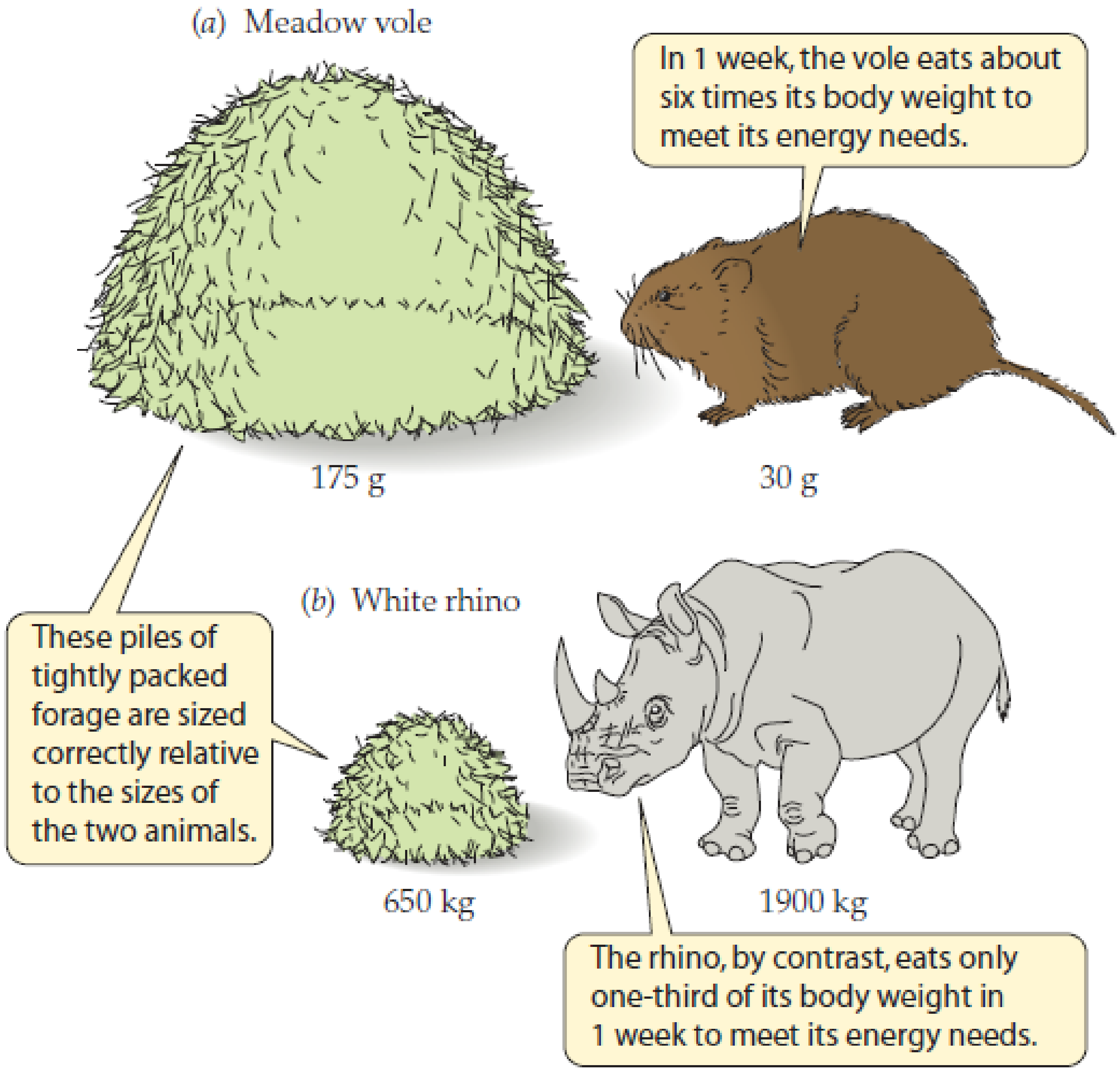
**TABLE 7.3** Some factors that affect the metabolic rates of individual animals

| Factor | Response of metabolic rate | Chapter(s) where discussed in this book |
|---|---|---|
| **Factors that exert particularly large effects** | | |
| Physical activity level (e.g., running speed) | ↑ with rising activity level | 8, 9 |
| Environmental temperature | *Mammals and other homeotherms:* | 10 |
| | Lowest in thermoneutral zone | |
| | ↑ below thermoneutral zone | |
| | ↑ above thermoneutral zone | |
| | *Fish and other poikilotherms:* | |
| | ↑ with increasing temperature | |
| | ↓ with decreasing temperature | |
| **Factors that exert smaller effects** | | |
| Ingestion of a meal (particularly protein-rich) | ↑ for several hours to many hours following ingestion | 7 |
| Body size | Weight-specific rate ↑ as size ↓ | 7 |
| Age | Variable; in humans, weight-specific rate ↑ to puberty, then ↓ | — |
| Gender | Variable; in humans, ↑ in male | — |
| Environmental $O_2$ level | Often ↓ as $O_2$ ↓ below a threshold; not affected above threshold | 8, 23 |
| Hormonal status | Variable; example: ↑ by excessive thyroid secretions in mammals | 16 |
| Time of day | Variable; in humans, ↑ in daytime | 15 |
| Salinity of water (aquatic animals) | Variable; in osmoregulating marine crabs, ↑ in dilute water | 28 |

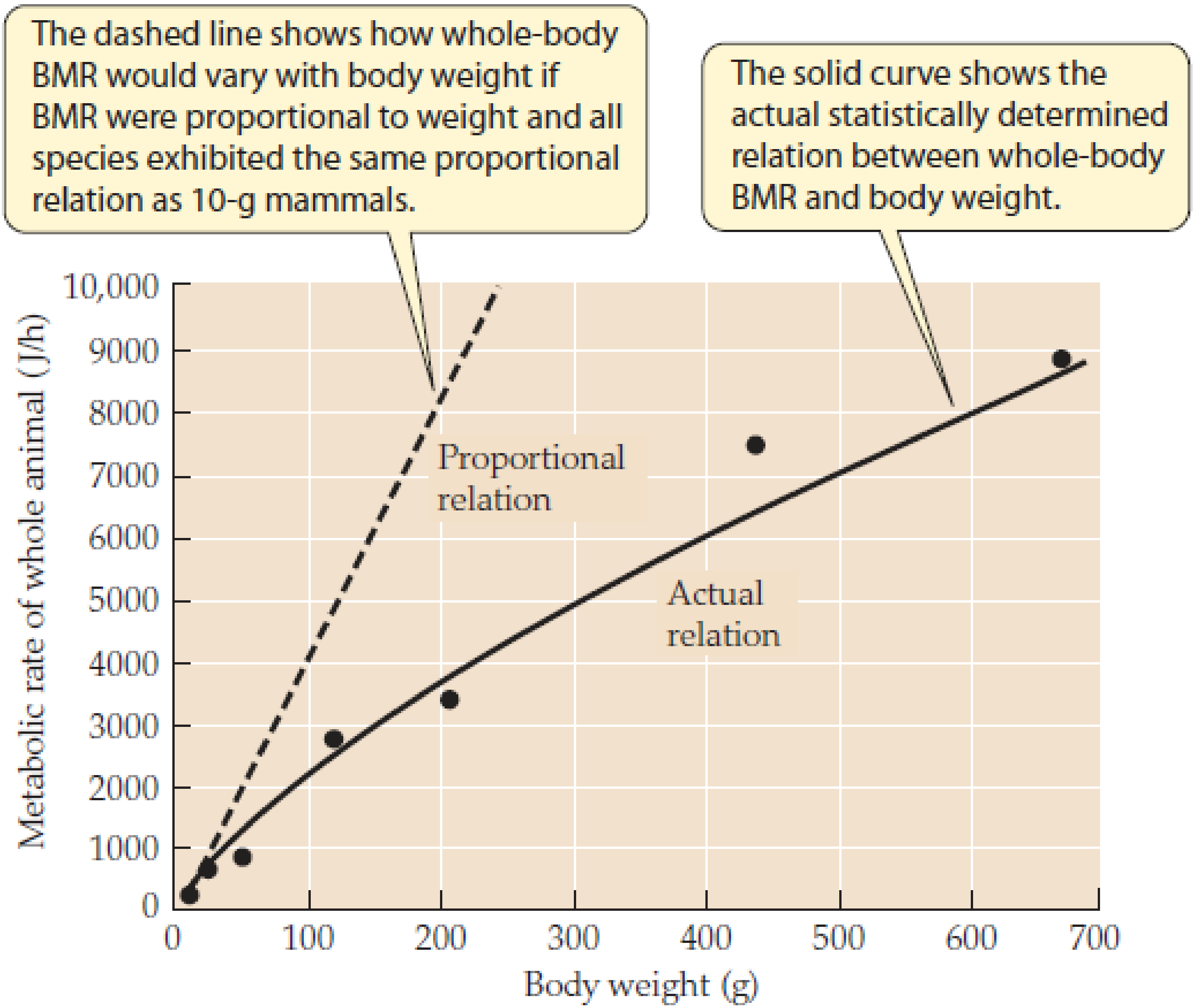
# Basal & Standard Metabolic Rate

- The basal metabolic rate (BMR) is a standardized measure of metabolic rate that applies to *homeotherms*
  - The basal metabolic rate of a homeotherm is the animal's metabolic rate while it is (1) in its thermoneutral zone, (2) fasting, and (3) resting.
- Standard metabolic rate (SMR) applies to *poikilotherms* (*ectotherms*)
  - The standard metabolic rate is the metabolic rate of a poikilothermic animal while it is (1) fasting and (2) resting.

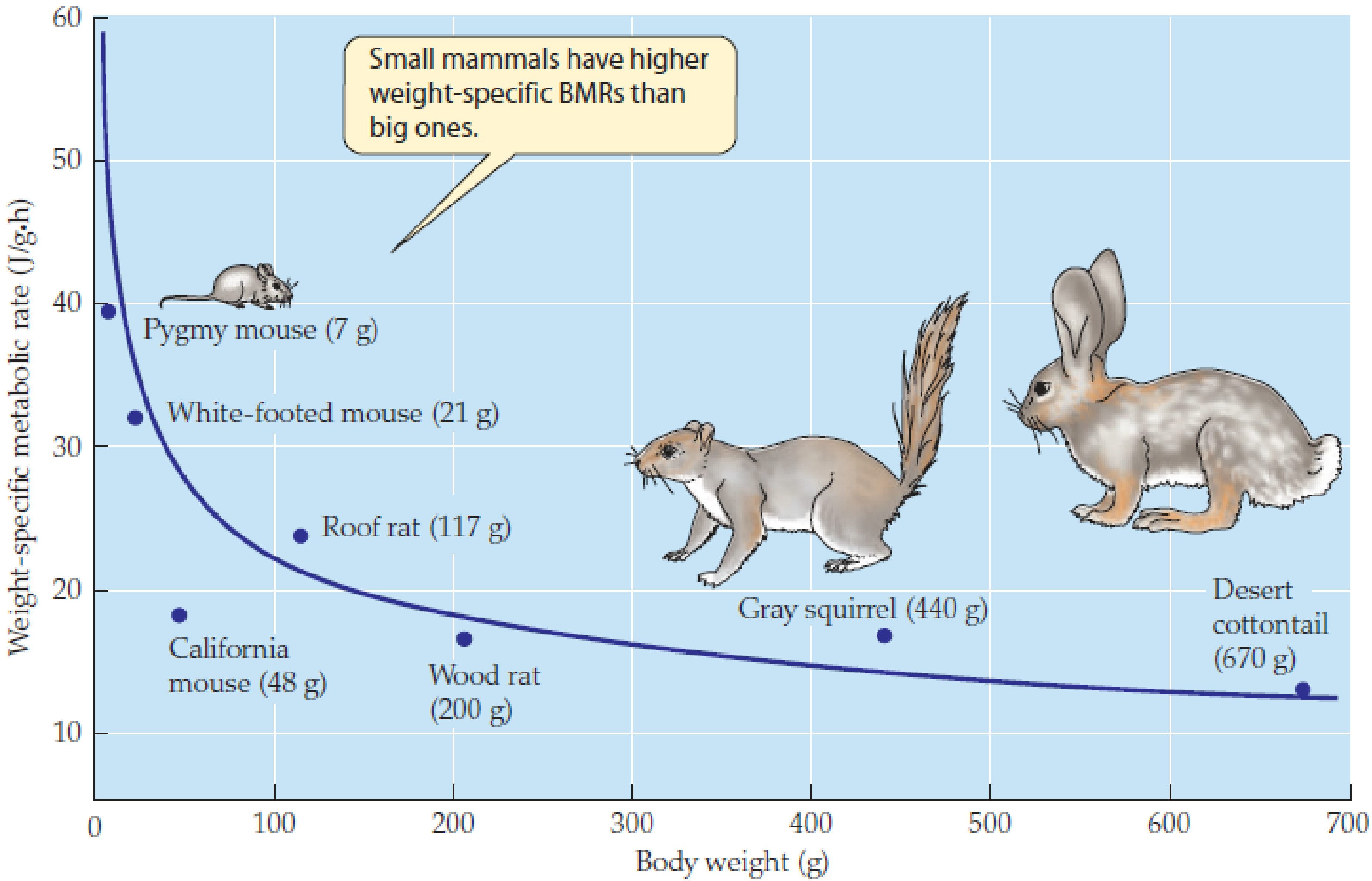
# Metabolic Scaling



# Relationship between body weight and metabolic rate

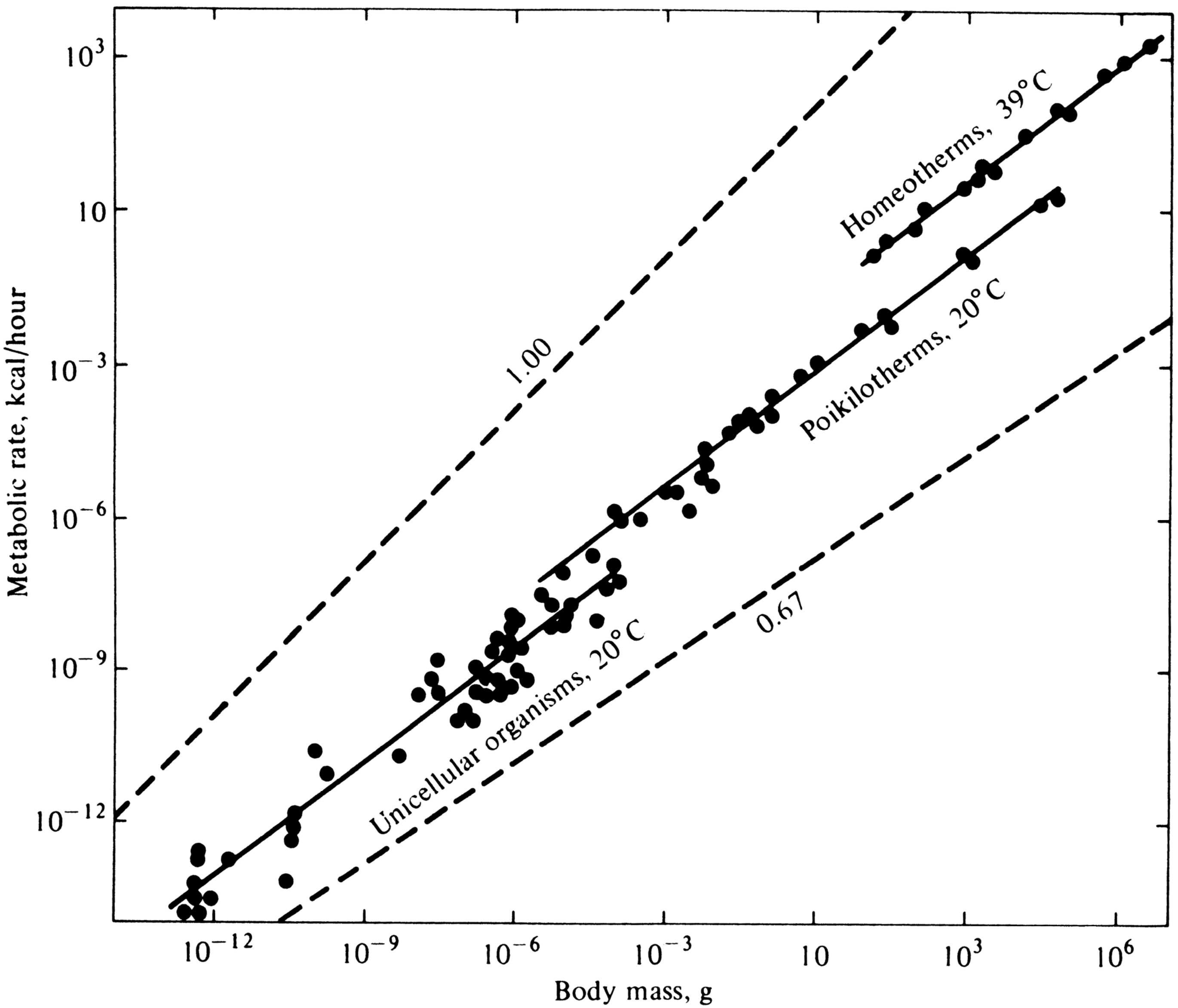


# Mammals



Small mammals have higher weight-specific BMRs than big ones.
Weight-specific metabolic rate (J/g•h)
60
50
40
30
20
10
Pygmy mouse (7 g)
White-footed mouse (21 g)
Roof rat (117 g)
California mouse (48 g)
Wood rat (200 g)
Gray squirrel (440 g)
Desert cottontail (670 g)
0
100
200
300
400
500
600
700
Body weight (g)

# In different kinds of animals



# Physiological consequence

**TABLE 7.4** Resting heart rate, and heart size relative to body weight, in seven species of mammals

| Species and average body weight | Resting heart rate (beats/min)[a] | Heart weight per unit of body weight (g/kg)[b] |
|---|---|---|
| African elephant (4100 kg) | 40 | 5.5 |
| Horse (420 kg) | 47 | 7.5 |
| Human (69 kg) | 70 | 5.2 |
| Domestic dog (19 kg) | 105 | 9.2 |
| Domestic cat (3 kg) | 179 | 4.1 |
| Roof rat (0.34 kg) | 340 | 2.9 |
| Lab mouse (0.03 kg) | 580 | 4.0 |

# Ecological consequence

**TABLE 7.5** **Biomasses of populations of selected herbivores living in mixed communities in African national parks**

Species are listed in order of increasing individual size. These species were chosen for listing because they are statistically about average in population biomass for their body sizes.

| Species | Average biomass of entire population per square kilometer ($kg/km^2$) | Average individual body weight (kg) |
|---|---|---|
| Oribi (*Ourebia ourebi*) | 44 | 13 |
| Gray duiker (*Sylvicapra grimmia*) | 62 | 16 |
| Gray rhebok (*Pelea capreolus*) | 105 | 25 |
| Warthog (*Phacochoerus aethiopicus*) | 95 | 69 |
| Waterbuck (*Kobus ellipsiprymnus*) | 155 | 210 |
| Greater kudu (*Tragelaphus strepsiceros*) | 200 | 215 |
| Plains zebra (*Equus burchelli*) | 460 | 275 |
| White rhino (*Ceratotherium simum*) | 2400 | 1900 |
| African elephant (*Loxodonta africana*) | 1250 | 3900 |

# The explanation: unknown

- We used to explain by *Rubner's surface "law."*
  - surface area $s$ of a sphere is proportional to the square of $r$, the sphere's radius: $s \propto r^2$.
  - The volume $v$ of a sphere, however, is proportional to the cube of the radius: $v \propto r^3$.
  - Therefore $s \propto v^{2/3}$
  - In words, as spheres increase in size, their surface area increases only as the two-thirds power of their volume.

# It made sense

- Placental mammals maintain high, relatively constant body temperatures (near 37°C) and thus tend to lose heat to the environment when studied at thermoneutral environmental temperatures.
- Because heat is lost across an animal’s outer body surfaces, the rate of heat loss from a mammal is approximately proportional to the animal’s body-surface area.
- Small mammals have more surface area per unit of weight than do large mammals and thus lose heat more rapidly per unit of weight.
- Heat lost must be replaced metabolically for a mammal to stay warm. Accordingly, small mammals must produce heat at a greater rate per unit of weight than large ones.
  - So we try to be big

# But

- poikilothermic animals—such as fish, frogs, and crabs—display allometric metabolism–size relations
  - But they do not control heat anyway

- There are some other hypothesis for explanation but none is suitable
  - **So we think there are more than one reason**

# Text: Hill

Images: Hill, www