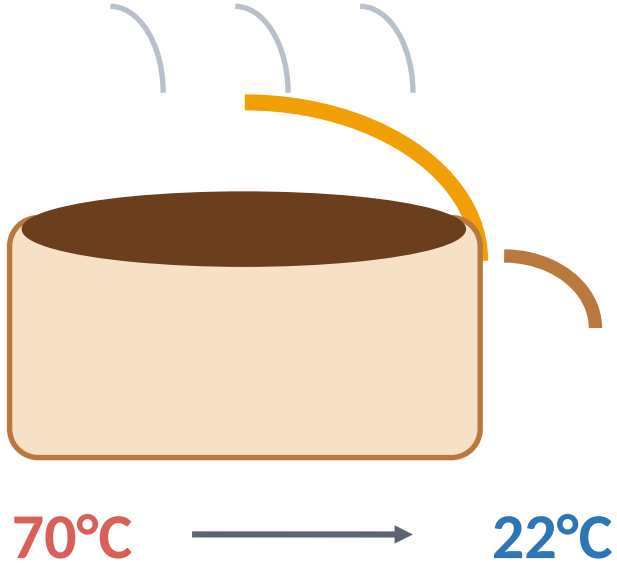
Thermodynamics in Living Cells

Four simple ideas

Why does hot coffee cool down by itself?

This simple question leads us to the rules of energy transformation in biology.



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Senior Lecturer

1. What is energy?

Energy exists in different forms, but cells must convert it into usable forms.

Energy = capacity to do work

Chemical

Glucose, fatty acids

Light

Sunlight

Electrochemical

Proton gradient

Mechanical

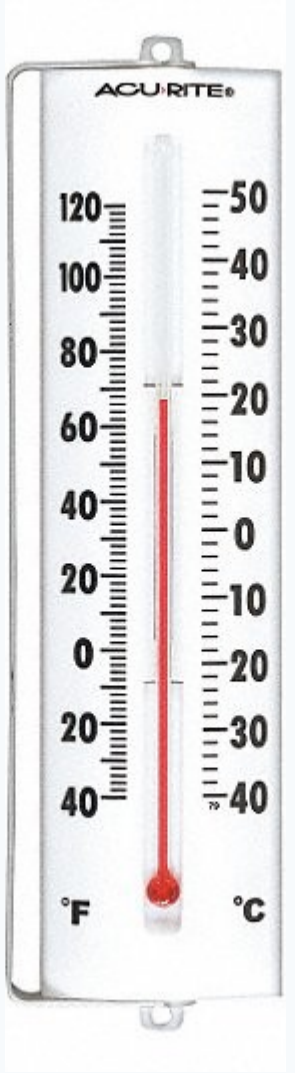
Movement

Heat

Body temperature

Bioenergetics asks: How does the cell convert one form of energy into another?

Zeroth Law of Thermodynamics
If two systems are each in thermal equilibrium with a third system, they are in thermal equilibrium with each other.
System A ⇄ System C
System B ⇄ System C
Therefore:
System A ⇄ System B
Key idea:
Thermal equilibrium means equal temperature.

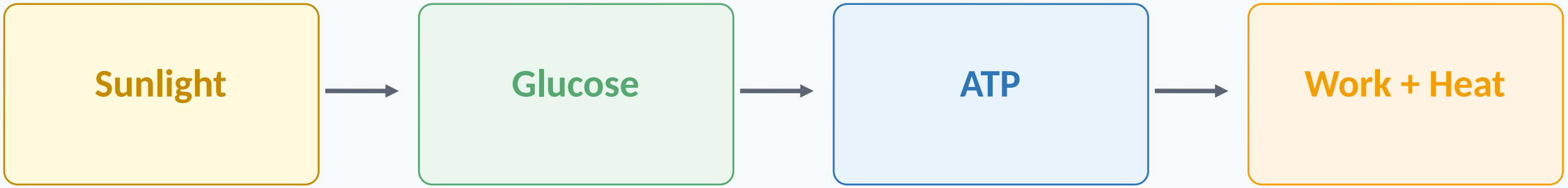


A cell placed in an environment at constant temperature will eventually reach thermal equilibrium with its surroundings.

2. First Law of Thermodynamics

Energy does not disappear — it changes form.

ENERGY CANNOT BE CREATED OR DESTROYED



Same energy — different form

In a living cell, energy is transformed rather than lost.

Biological example: energy from food

Follow the energy from breakfast to cellular work.



First Law message: Food energy is not “used up” and destroyed — it is converted into ATP, work, and heat.

3. Second Law of Thermodynamics

Energy transformations are not 100% efficient.

Everyday example



HOT

Heat spreads to the room

Biological example

Energy in food → ATP + cell work

Energy in food → HEAT

Some energy becomes dispersed and less available for useful work.

Third Law of Thermodynamics
The entropy of a perfect crystal approaches zero as the temperature approaches absolute zero (0 K).

$T \rightarrow 0\ K \rightarrow S \rightarrow 0$
- **T** = absolute temperature
- **S** = entropy
- **0 K = −273.15°C**

- Molecular motion becomes minimal at very low temperature
- The system approaches its most ordered state
- Entropy reaches its minimum value
- Absolute zero cannot be reached by a finite number of processes

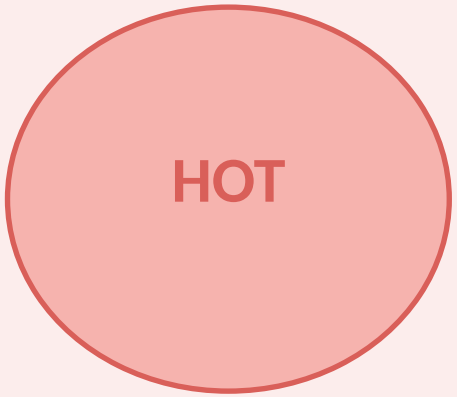
- Biological systems cannot function near absolute zero
- Low temperature strongly slows molecular motion and biochemical reactions
- The law provides a reference point for calculating **absolute entropy**

Entropy

For this course: entropy is related to how widely energy is dispersed.

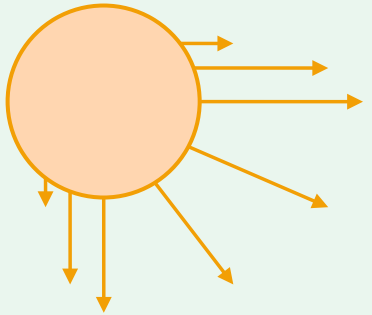
LOWER DISPERSAL

Energy concentrated in one place



MORE DISPERSAL

Energy spread through surroundings



Cells stay organized by taking in energy and releasing heat + waste.

Why does thermodynamics matter in biology?

It helps us ask the right questions about cellular reactions.

1. **Does this process release energy?**

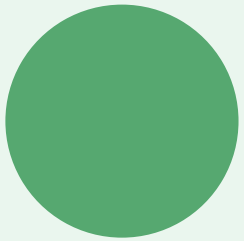
2. **Does this process require energy?**

3. **Can the cell couple it to another process?**

Thermodynamics does not tell us how fast a reaction is — that is kinetics.

4. Gibbs Free Energy (ΔG)

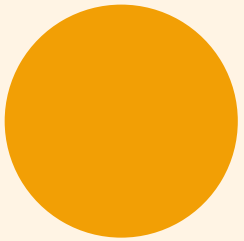
Use ΔG as a simple “energy traffic light.”



ΔG < 0

GO

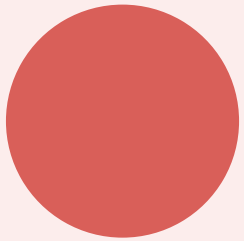
Energetically favorable



ΔG = 0

STOP / BALANCE

Equilibrium



ΔG > 0

NEEDS ENERGY

Energy input required

Important: ΔG < 0 means favorable, NOT necessarily fast. Enzymes change rate, not the overall ΔG.

Exergonic vs Endergonic Reactions

Two words, one simple difference.

EXERGONIC

ΔG < 0

Releases free energy

Examples:
- Glucose oxidation
- ATP hydrolysis

ENDERGONIC

ΔG > 0

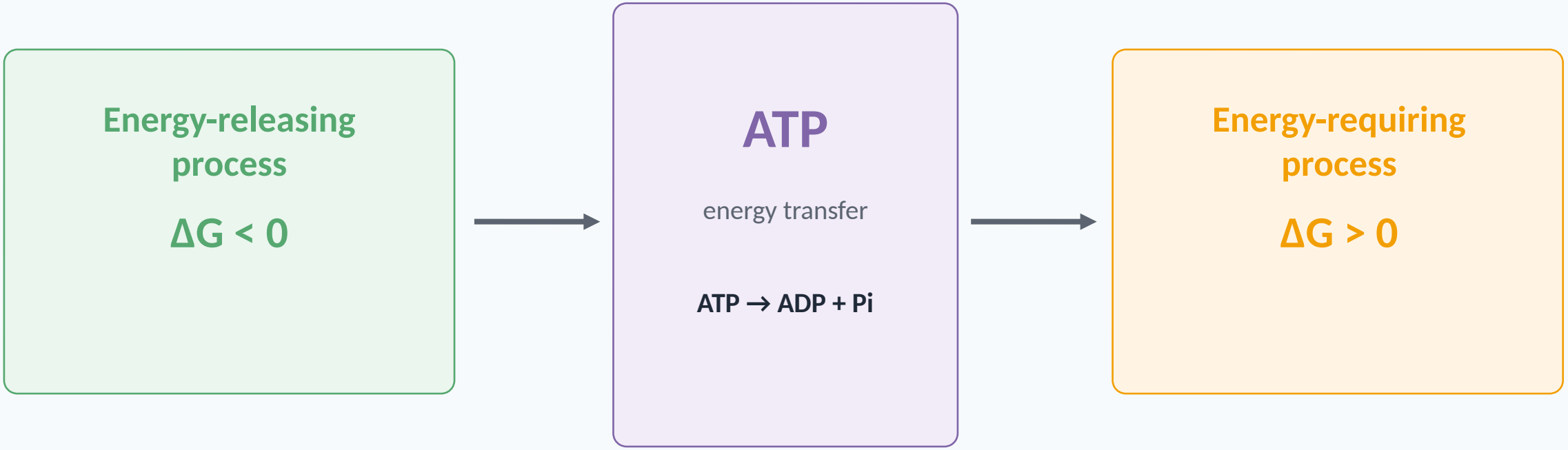
Requires energy

Examples:
- Active transport
- Biosynthesis

Cells survive because they connect these two types of processes.

The central idea: Energy Coupling

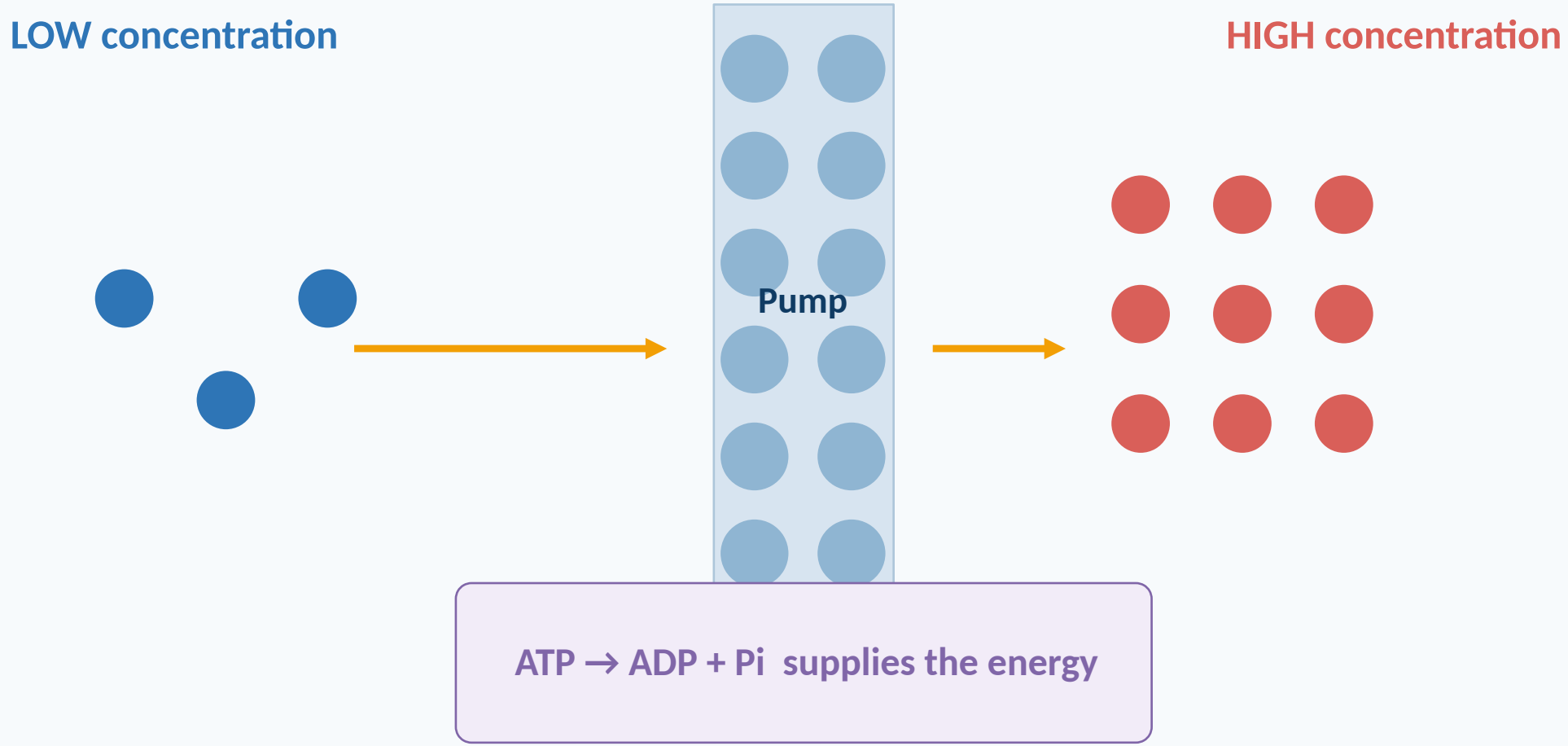
Cells use an energy-releasing process to drive an energy-requiring process.



One favorable process can drive another process that needs energy.

Example: ATP drives active transport

Moving molecules against a gradient requires energy.



Against the gradient = endergonic → ATP coupling makes it possible.

Take-home message

1 **Energy is conserved** — It changes form; it does not disappear.

2 **Energy becomes dispersed** — Some energy is released as heat.

3 **ΔG tells direction** — Negative = favorable; positive = needs energy.

4 **Cells couple reactions** — ATP often connects energy release to cell work.

Quick check: ΔG = −15? → favorable | ΔG = +12? → needs energy | ATP? → energy coupling