# PHYS11 CH:12 The Universe's Accounting System

## How Energy Becomes Unavailable

Mr. Gullo

December 2025

# Outline

# The Mystery of the Perfect Engine

What if you could build an engine

*that converts all heat into work?*

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Engineers have been trying for 300 years...

Nature says: Impossible.

# Energy Transforms


Figure: Steam engine: burning fuel transfers heat to do work

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**The challenge:** Most thermal energy escapes as waste heat.

# Learning Objectives

By the end of this section, you will be able to:

- **12.1:** Explain the zeroth law of thermodynamics

### The Mental Model

Place ice in warm water. What happens?

# 12.1 When Things Stop Changing

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**Nature's Rule**

They are now in **thermal equilibrium**.

## Universal Law: The Transitive Property

If system A is in thermal equilibrium with system B,
and B is in thermal equilibrium with system C,
then A is also in thermal equilibrium with C.

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Why "zeroth"? Discovered after first and second laws, but more fundamental.

# 12.1 Real-World: Neonatal Incubators

Figure: Premature baby in incubator

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**Zeroth law in action:**
Air, incubator walls, and baby all reach thermal equilibrium at safe temperature.

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Fortunately! Otherwise Earth would be as hot as sun's surface ($\sim$5800 K).

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- **12.2:** Describe pressure-volume work
- **12.2:** State first law verbally and mathematically
- **12.2:** Solve first law problems

# 12.2 Pressure: Force over Area

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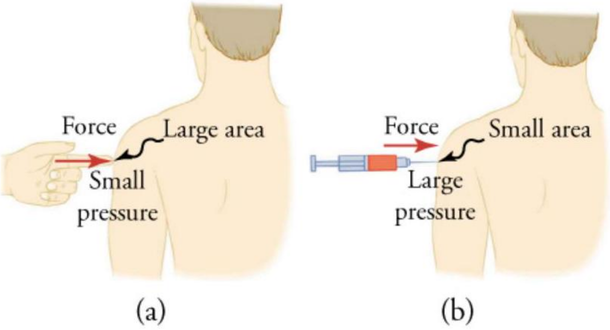
**SI unit:** Pascal (Pa), where $1 \text{ Pa} = 1 \text{ N/m}^2$

# 12.2 Same Force, Different Pressure



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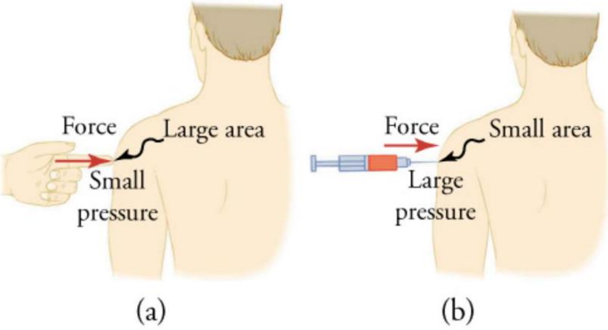


**Civilian View vs. Reality**

**Civilian:** "The needle pushes harder."
**Physicist:** "Same force, smaller area = higher pressure."

# 12.2 The Ideal Gas Law

## Universal Law: Gas Behavior

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Pressure times volume equals particles times Boltzmann constant times absolute temperature.

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Where:

- $P$ = pressure (Pa)
- $V$ = volume ($m^3$)
- $N$ = number of particles
- $k = 1.38 \times 10^{-23}$ J/K (Boltzmann constant)
- $T$ = absolute temperature (K)

# 12.2 Gas Law Relationships

For fixed amount of gas:

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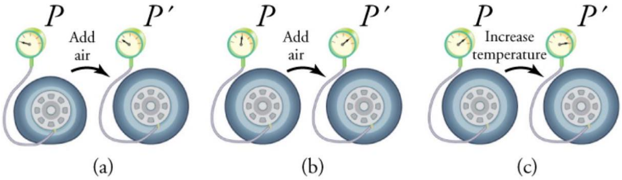
**The Mental Model**

Pumping tire: volume increases, then pressure builds, tire warms up.

# 12.2 Pumping a Tire



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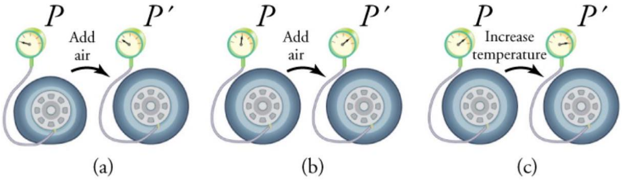


(a) Volume increases. (b) Pressure increases. (c) Temperature increases.

# 12.2 Pressure-Volume Work

Figure: Gas expansion does work pushing piston

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## Nature's Rule for Gases

$$\boxed{W = P\Delta V}$$

Work equals pressure times change in volume.

# 12.2 The First Law of Thermodynamics

## Universal Law: Energy Conservation

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This is conservation of energy for thermal systems.

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# 12.2 Understanding the Signs

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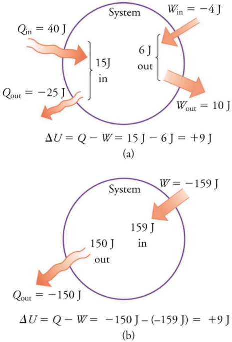
**Key Insight**

Positive $Q$ adds energy. Positive $W$ removes energy.




$Q$ in adds energy. $W$ out removes energy. $\Delta U$ is net change.

# Attempt: Energy Accounting

## The Challenge (3 min, silent)

System absorbs 40.0 J of heat, does 10.0 J of work.
Later, 25.0 J heat leaves, 4.0 J work done ON system.

**Find:** Net change in internal energy $\Delta U$

*Can you track energy? Work silently.*

# Compare: Energy Tracking

**Turn and talk (2 min):**

1. What was net heat $Q$? How calculate?
2. What was net work $W$? Signs correct?
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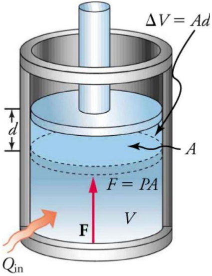
**Check:** More heat in than work out → internal energy increases.

# 12.2 Biology: Your Body as Heat Engine



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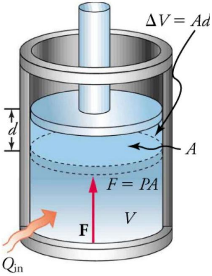


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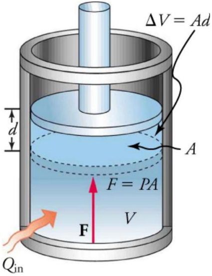


$$\Delta U = Q - W + \text{food energy}$$

- Food adds chemical potential energy
- Work (exercise) removes energy
- Heat (body temp) removes energy
- Leftover stored as fat

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Nature has preferred direction.

# 12.3 Entropy: Measure of Disorder

**Definition: Entropy**

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**SI unit:** J/K (joules per kelvin)

# 12.3 Ice Melting: Entropy Increases

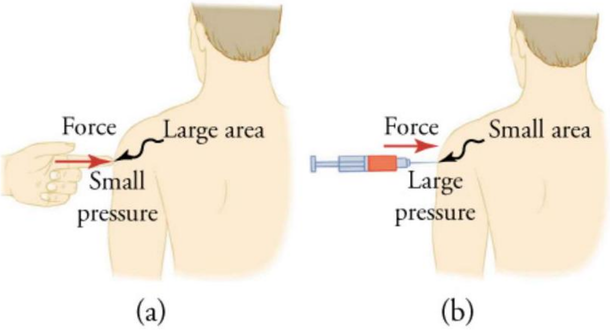
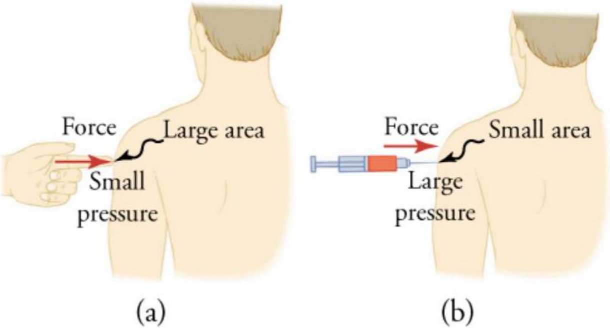



Figure: Ice melts: ordered crystal becomes disordered liquid

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**Entropy increases because:**

- Structured ice → random liquid
- System becomes more disordered

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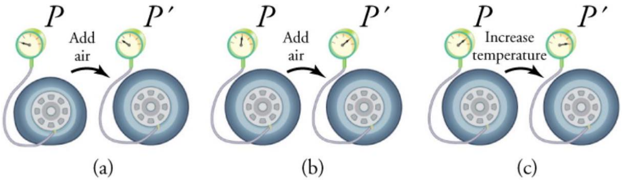
**Key Consequences**

- Heat flows spontaneously hot to cold, never cold to hot
- Energy becomes less available over time
- Disorder increases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Add
air
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P
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air
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Increase
temperature
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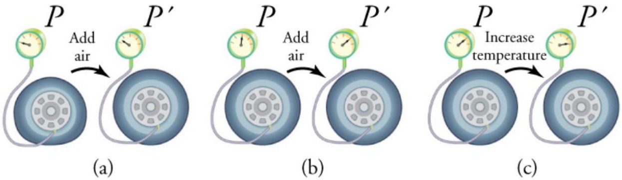
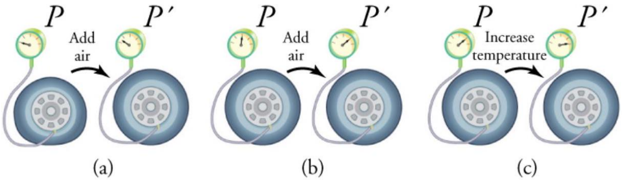
(a)
(b)
(c)

# 12.3 Heat Flow and Entropy




**Why heat flows hot to cold:**

Larger entropy increase at low T than decrease at high T.




**Why heat flows hot to cold:**

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$$\Delta S = \frac{Q}{T} \rightarrow \text{smaller } T \text{ means larger } \Delta S$$

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## Local Entropy Decrease Examples

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In all cases, environment entropy increases MORE than system entropy decreases.

# Attempt: Ice Melting Entropy

## The Challenge (3 min, silent)

Find entropy increase when 1.00 kg ice at 0°C melts to water at 0°C.

**Given:**

- Mass: $m = 1.00$ kg
- Temperature: $T = 0°\text{C} = 273$ K
- Latent heat fusion: $L_f = 334$ kJ/kg

**Find:** $\Delta S$

*Can you quantify disorder? Work silently.*

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# Reveal: Entropy of Melting

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$$Q = mL_f = (1.00)(334\ \text{kJ/kg}) = 3.34 \times 10^5\ \text{J}$$

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**Check:** Positive - disorder increased as ice melted.

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Machine that converts thermal energy into mechanical work using heat transfer.

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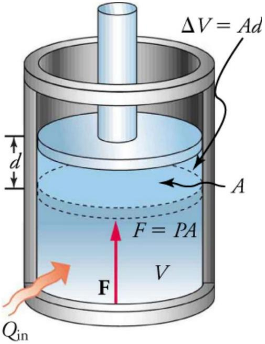
All use cyclical processes.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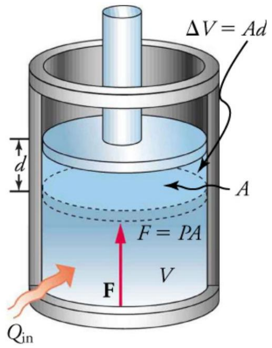
$d$
$A$
$F = PA$
$V$
$\mathbf{F}$
$Q_{in}$

# 12.4 How Heat Engines Work




1. Absorb heat $Q_h$ from hot reservoir
2. Do work $W$
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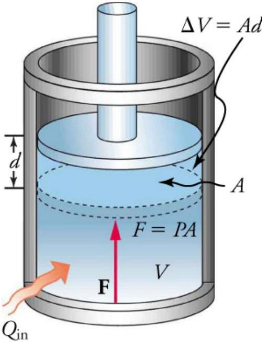


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100% impossible! (Second law forbids)

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**But second law says:**

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**Fundamental Limit**

Second law sets absolute ceiling on efficiency.

# Attempt: Power Plant Efficiency

## The Challenge (3 min, silent)

Coal plant absorbs $2.50 \times 10^{14}$ J, releases $1.48 \times 10^{14}$ J as waste in one day.

**Find:**

1. Work output $W$
2. Efficiency

*Can you measure wastefulness? Work silently.*

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Name wheel: One pair share approach (not answer).

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**Check:** Typical for coal. 59.2% wasted!

# 12.4 Heat Pumps and Refrigerators

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**Heat engines in reverse:**

- Use work to move heat cold to hot
- Refrigerators cool interior, warm exterior
- Heat pumps warm house using outside air

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## Universe's Accounting System

Energy conserved, but becomes less useful over time.

# Key Equations

$$P = \frac{F}{A} \quad \text{(Pressure)} \tag{1}$$

$$PV = NkT \quad \text{(Ideal gas)} \tag{2}$$

$$W = P\Delta V \quad \text{(P-V work)} \tag{3}$$

$$\Delta U = Q - W \quad \text{(First law)} \tag{4}$$

$$\Delta S = \frac{Q}{T} \quad \text{(Entropy)} \tag{5}$$

$$\text{Eff} = \frac{W}{Q_h} \quad \text{(Efficiency)} \tag{6}$$

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Second law gives time its direction.

# Homework

Complete assigned problems

posted on LMS