Thermal Metabolism Lab Activity (Introduction)

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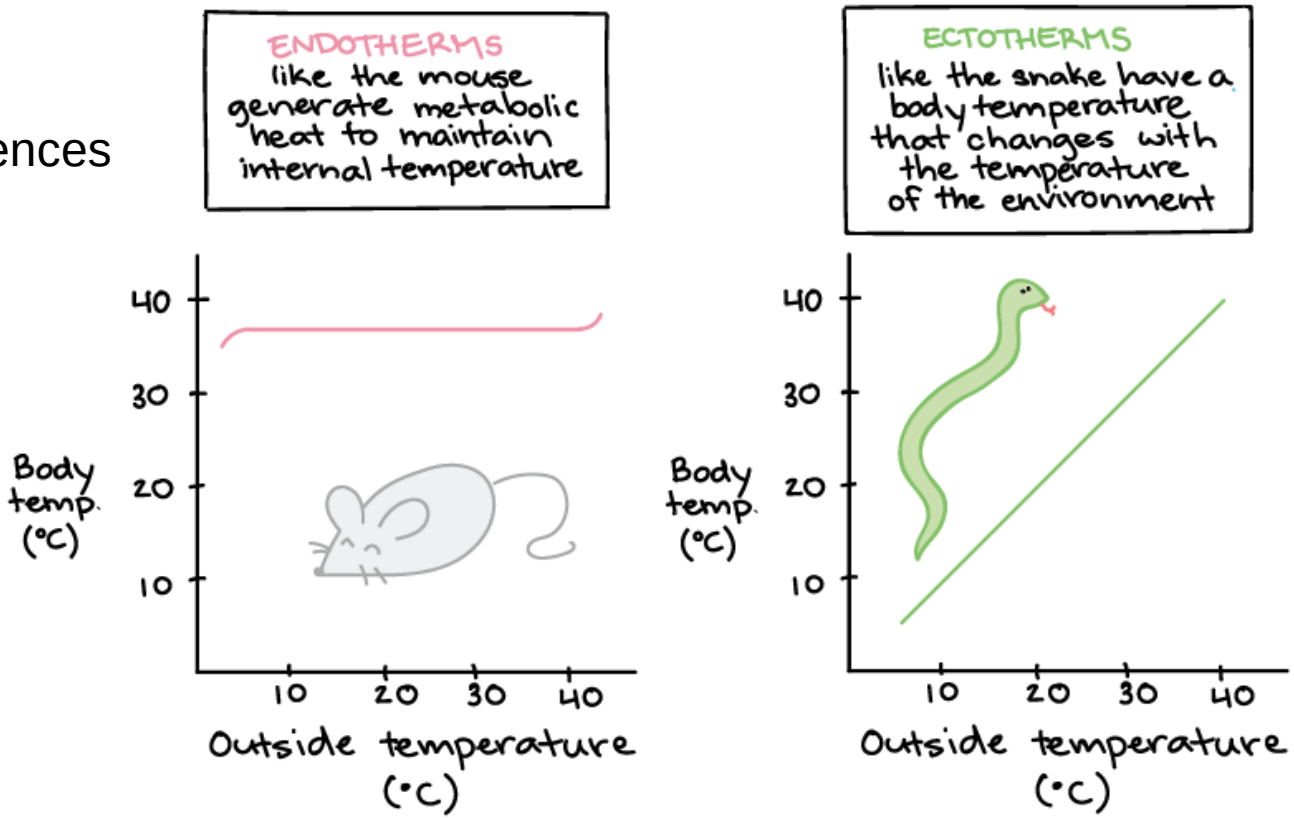


What is "Metabolism"?

Metabolism - set of chemical & physical processes needed to sustain life

Glucose metabolism:

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6H_20 + 6CO_2 + \text{energy}$$

(glucose + oxygen → water + carbon dioxide + energy)

Metabolic rate - how fast an organism burns up chemical energy to power its metabolism.

Research Question:

- Why do different animals have different metabolic responses to **temperature**?

Mammals

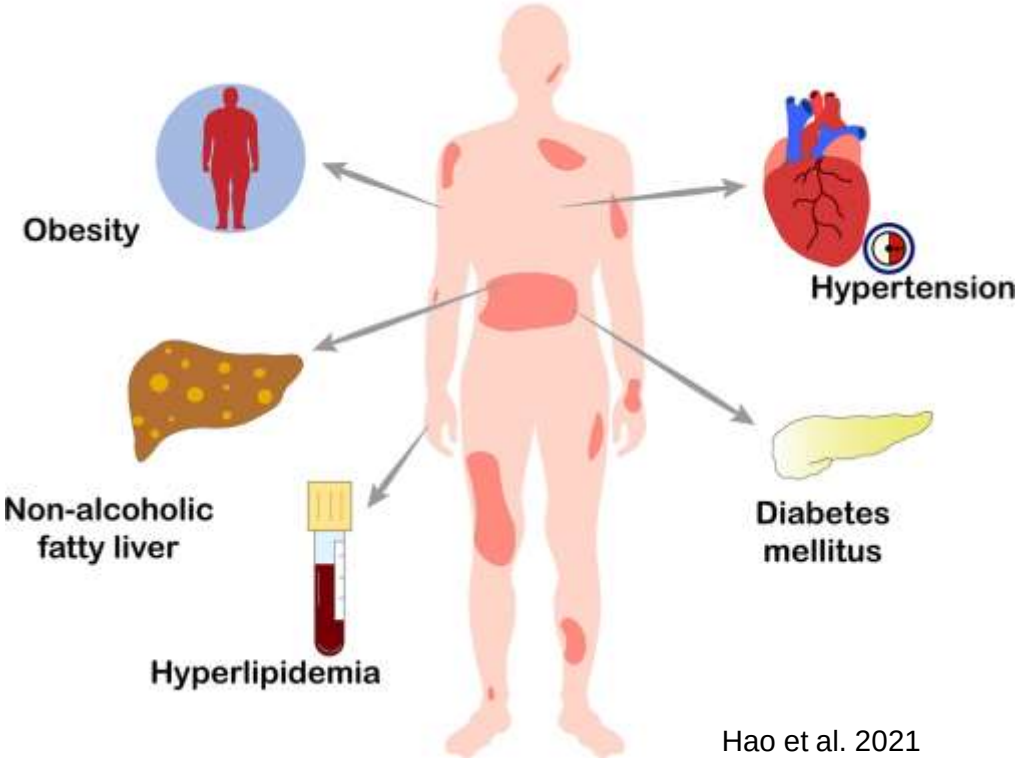
- Endothermic (endo = “internal”)
- Homeothermic (homeo = “constant”)

Frogs

- Ectothermic (ecto = “external”)
- Poikilothermic (poikilo = “variable”)

Why should we care?

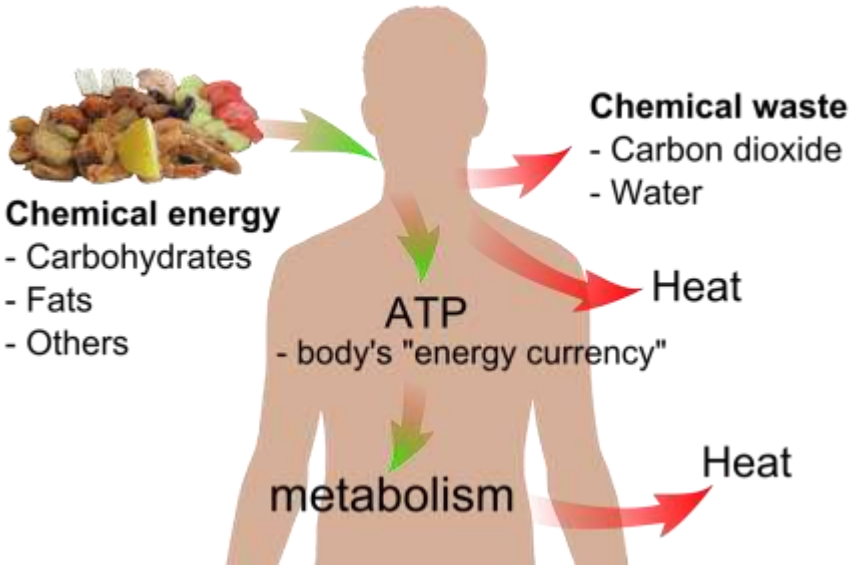
- **Health & Fitness**



Hao et al. 2021

Why should we care?

- Health & Fitness
- **Physics**



1st Law of Thermodynamics:

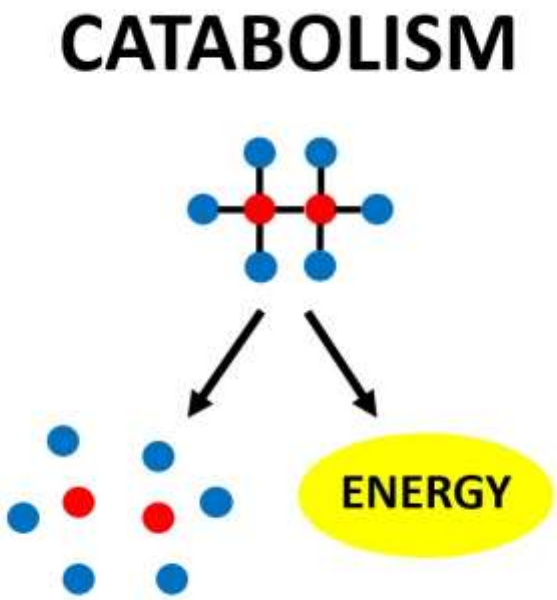
➢ Energy cannot be created or destroyed (but can change form)

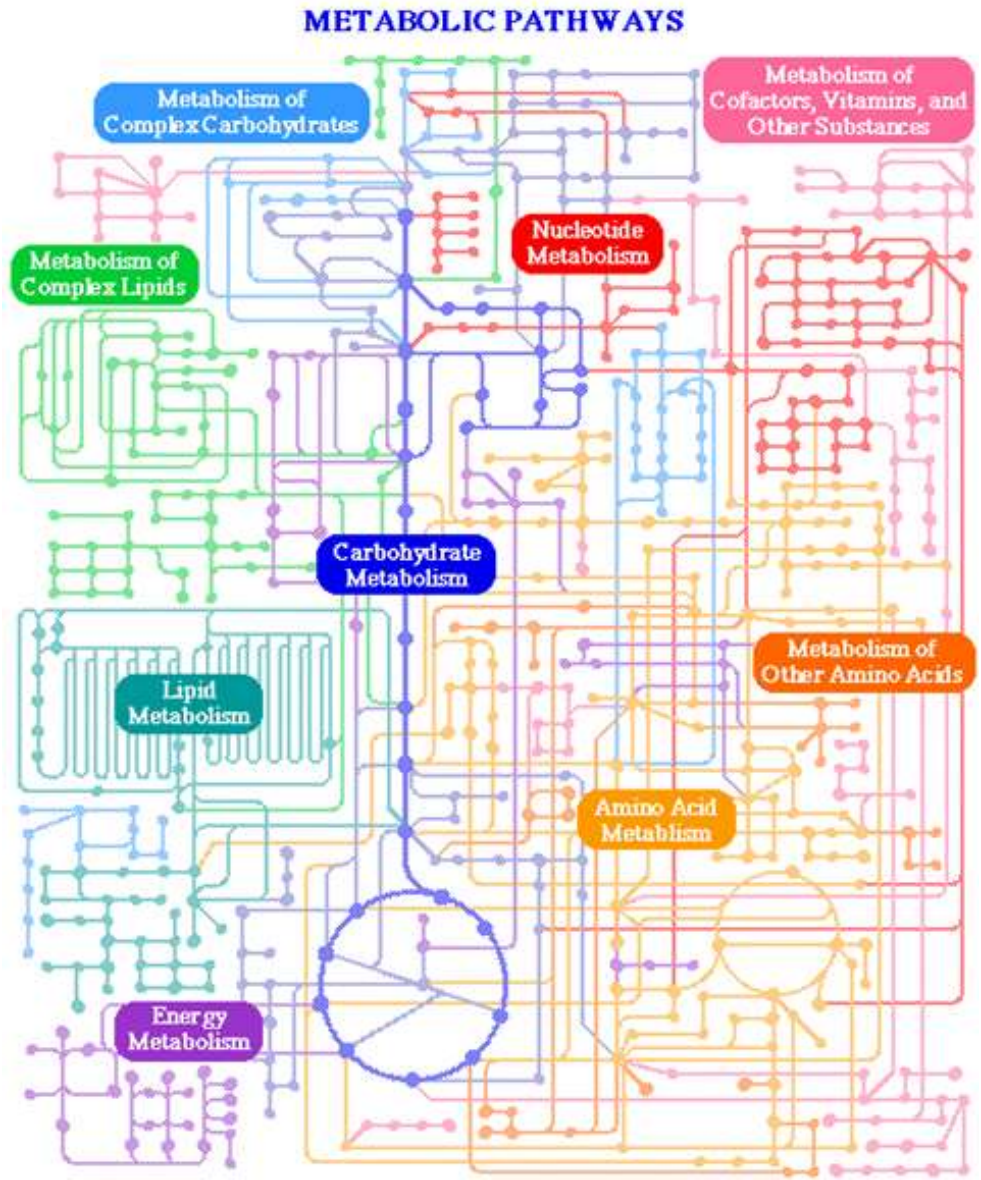
2nd Law of Thermodynamics:

➢ Heat tends to spread from warm areas to cool areas

Why should we care?

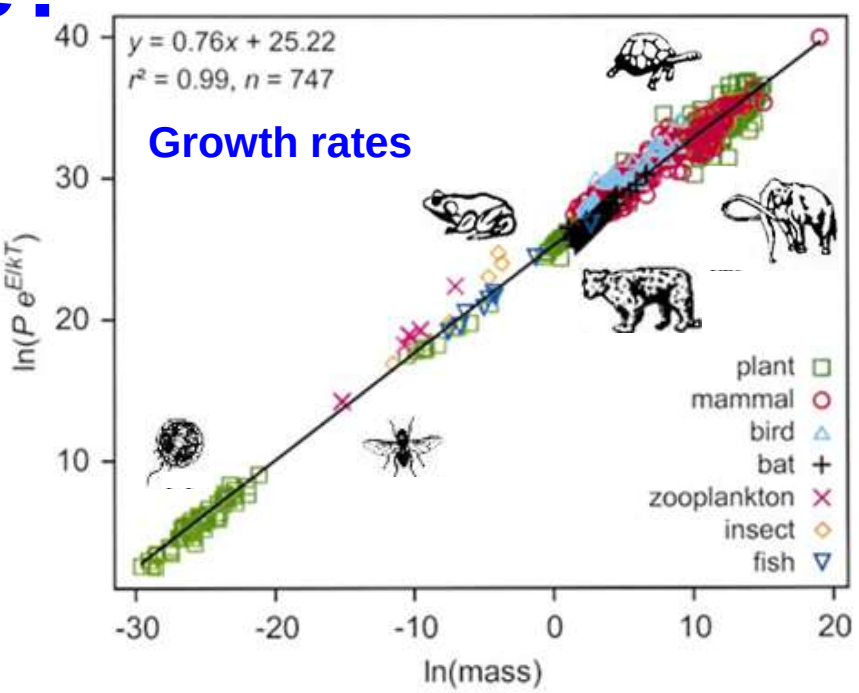
- Health & Fitness
- Physics
- **Chemistry**





Why should we care?

- Health & Fitness
- Physics
- Chemistry
- **Biology**

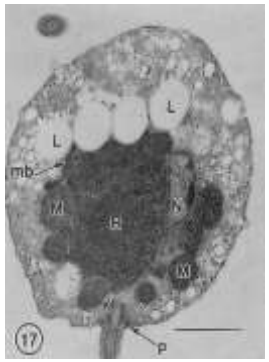


Brown et al. 2004

Metabolic Theory (MT) - proposes that mass-specific metabolic rates govern ALL PHYSIOLOGICAL AND ECOLOGICAL RATES

- Growth rate
- Development rate
- Movement rate (speed)
- **Heart rate**
- **Breath rate**

Why should we care?

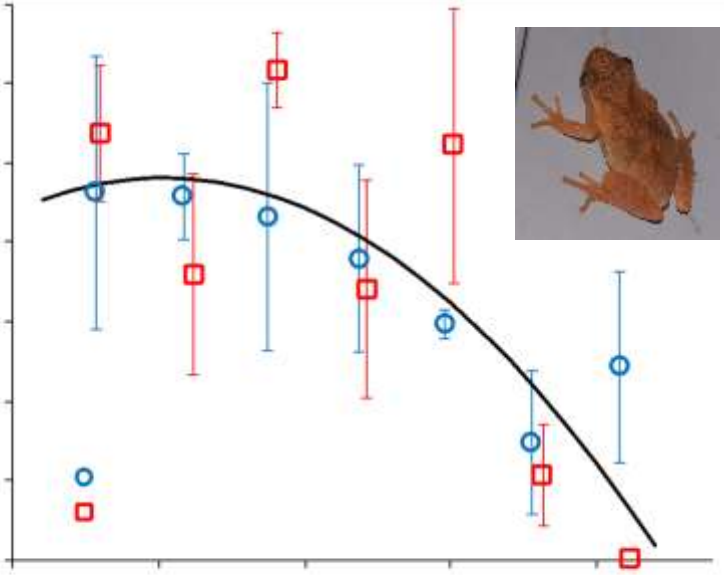


Longcore et al. 1999

RAFFEL LAB RESEARCH: Can we use Metabolic Theory to predict climate effects on a pandemic disease??

Chytridiomycosis

- Fungal skin infection
- Responsible for HUNDREDS of declines & extinctions
- Temperature-dependent – most infectious at cooler temperatures



Experimental data:

- Spring peepers, 7 days post-infection qPCR swabs
- Karie Altman 2017 experiment

Experiment 1:

- The following 3 objects have been sitting in the same place for a long time. Which is COLDEST (and why)?

1. Which FEELS COLDER when you touch it?

Copper pan

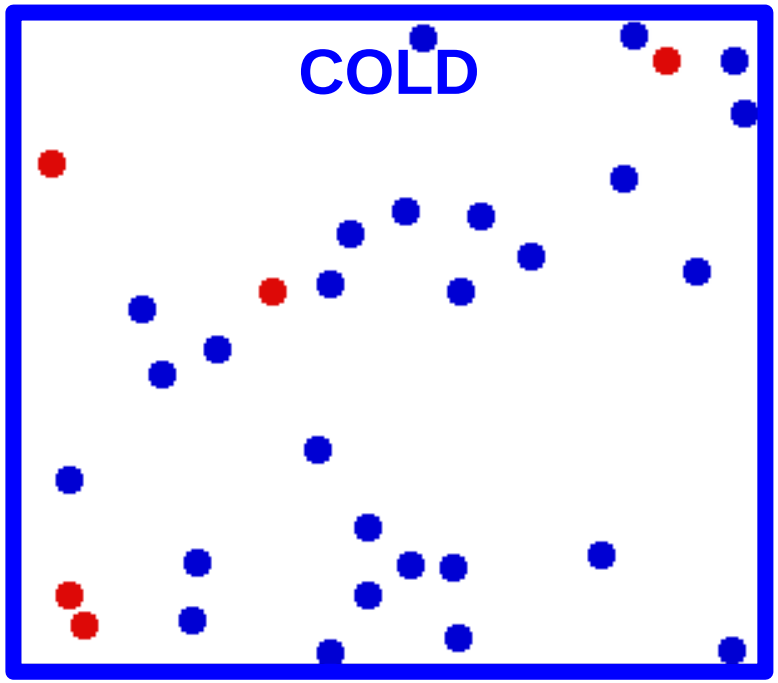
Water

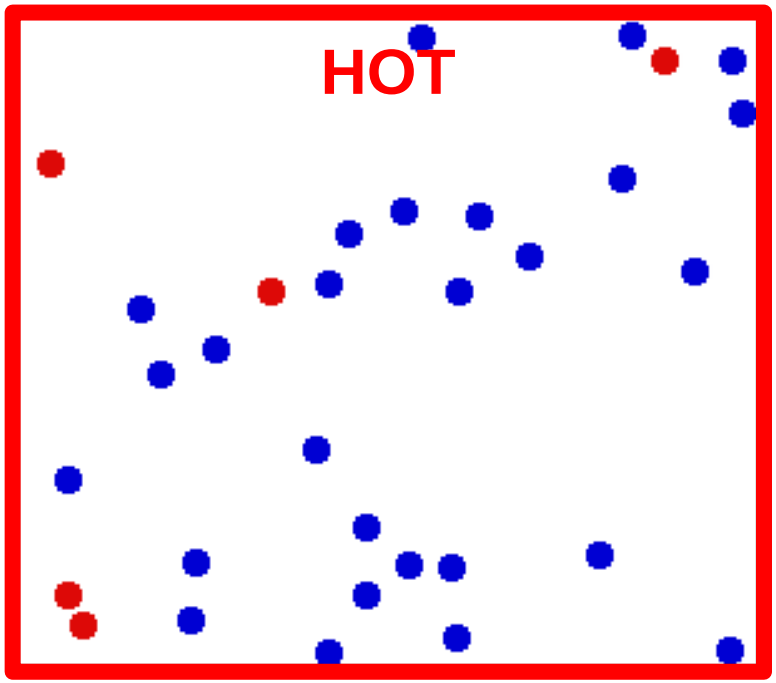
Neoprene glove

2. What are their ACTUAL temperatures (digital thermometer)

Intro to "Temperature" and HEAT:

- "Temperature" is actually a measurement of HEAT ENERGY!
- "Heat" is caused by MOLECULAR MOVEMENT within an object or substance. (i.e., heat is a type of kinetic energy!)

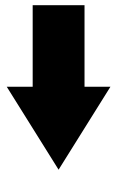




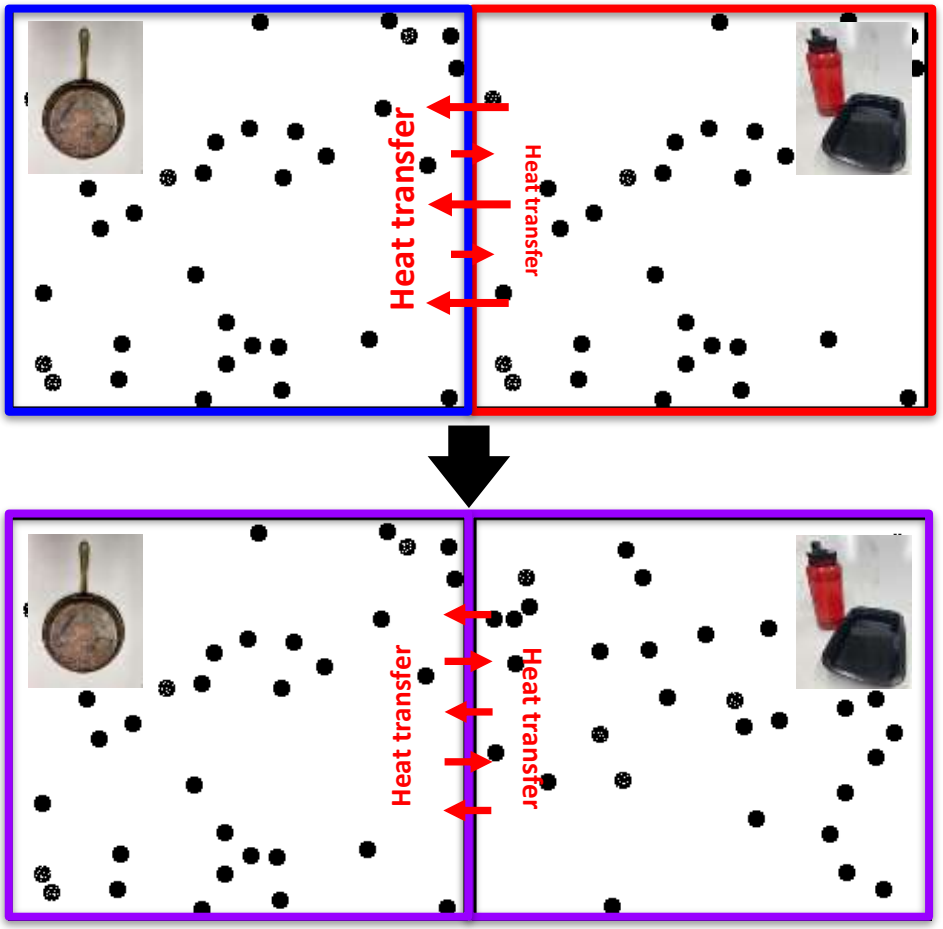
Intro to "Temperature" and HEAT:

- Why were all three objects at (roughly) the same temperature?
  - ➢ 2nd Law of Thermodynamics – heat spreads out due to random molecular movement, transferring from warm to cool areas.

More heat energy on the right side (more "organized"); more heat transfers left



Heat energy evenly spread out (less "organized"); heat transfers are balanced

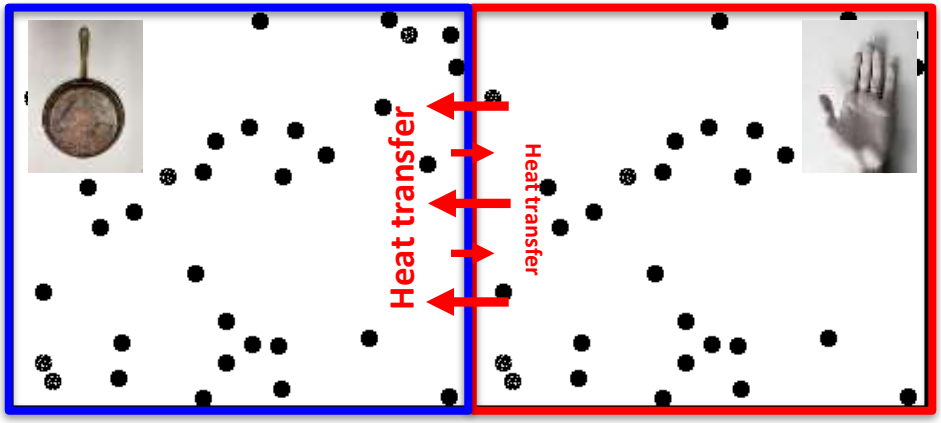


Intro to "Temperature" and HEAT:

- Why did the copper pan feel colder than the neoprene glove?
  - What your hand FEELS is loss of heat to the other object, which is faster for copper than for neoprene

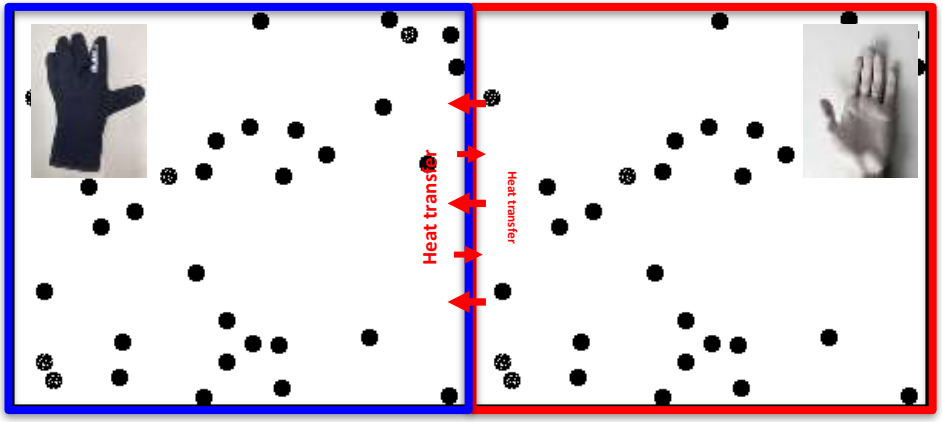
Copper has HIGH thermal conductance

- Rapid transfer of heat from hand to copper pan
- Neoprene feels "warm" (or at least not cold)



Neoprene has LOW thermal conductance

- SLOW transfer of heat
- Neoprene feels "neutral", even if its temperature is low!



OPEN QUESTION: (Brainstorm)

- What happens when a person puts their hand into COLD WATER?

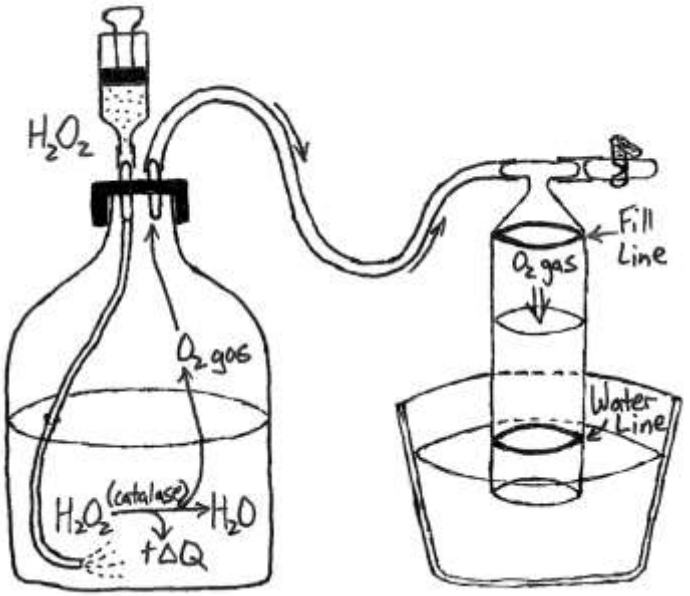
Image: Cold Pressor Test, Mythbusters with Kari Byron

Experimental Systems: (Biology)

- **Frog respiration (metabolic proxy)**

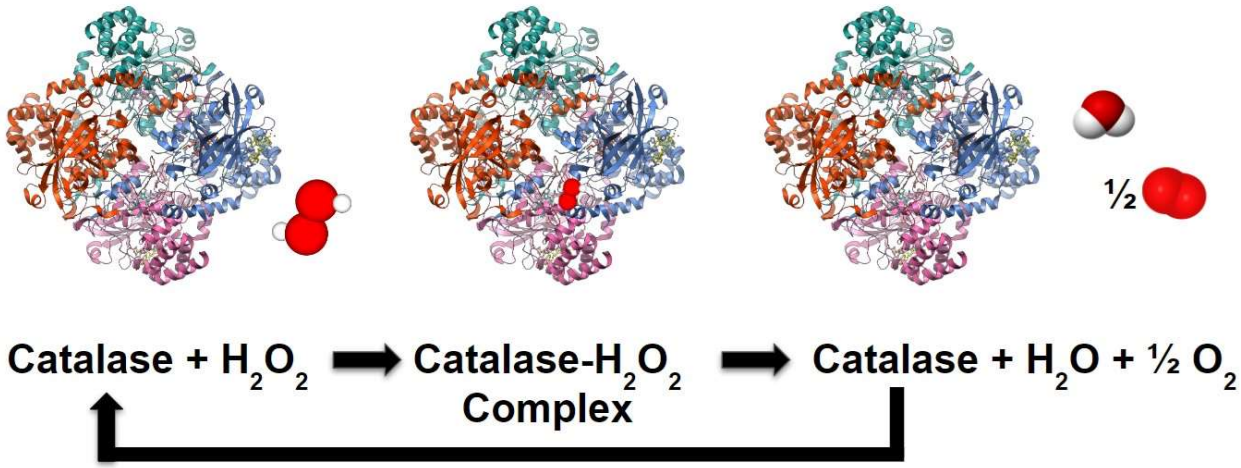
Experimental Systems: (Chemistry)

- **Hydrogen Peroxide decomposition**
  - ➢ Important metabolic reaction in your liver!



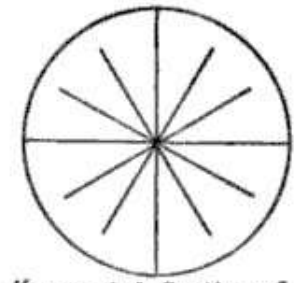
Catalase enzyme:

- Protein in liver; speeds up the chemical reaction, so we can measure it!

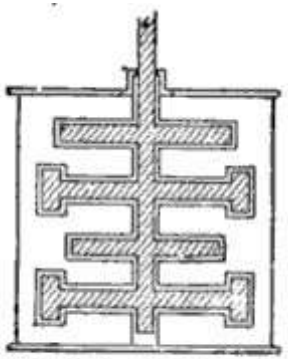


Experimental Systems: (Physics)

- **Joule apparatus**
  - Measures heat-energy equivalent of mechanical energy
  - How many times could an animal JUMP using the energy equivalent of heating their body by 1 C?

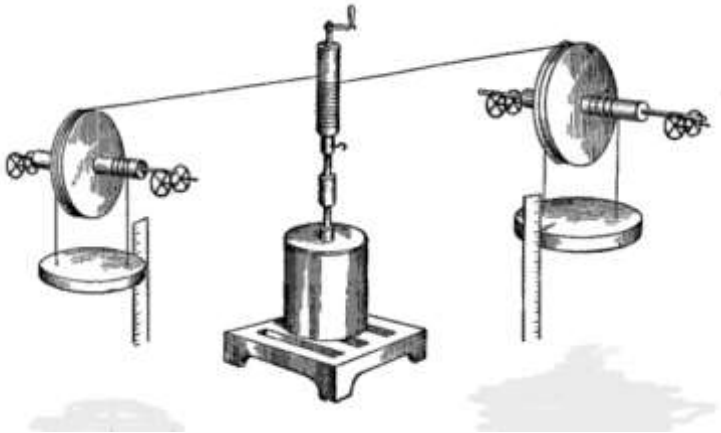


Horizontal Section of Calorimeter



Vertical Section of Calorimeter

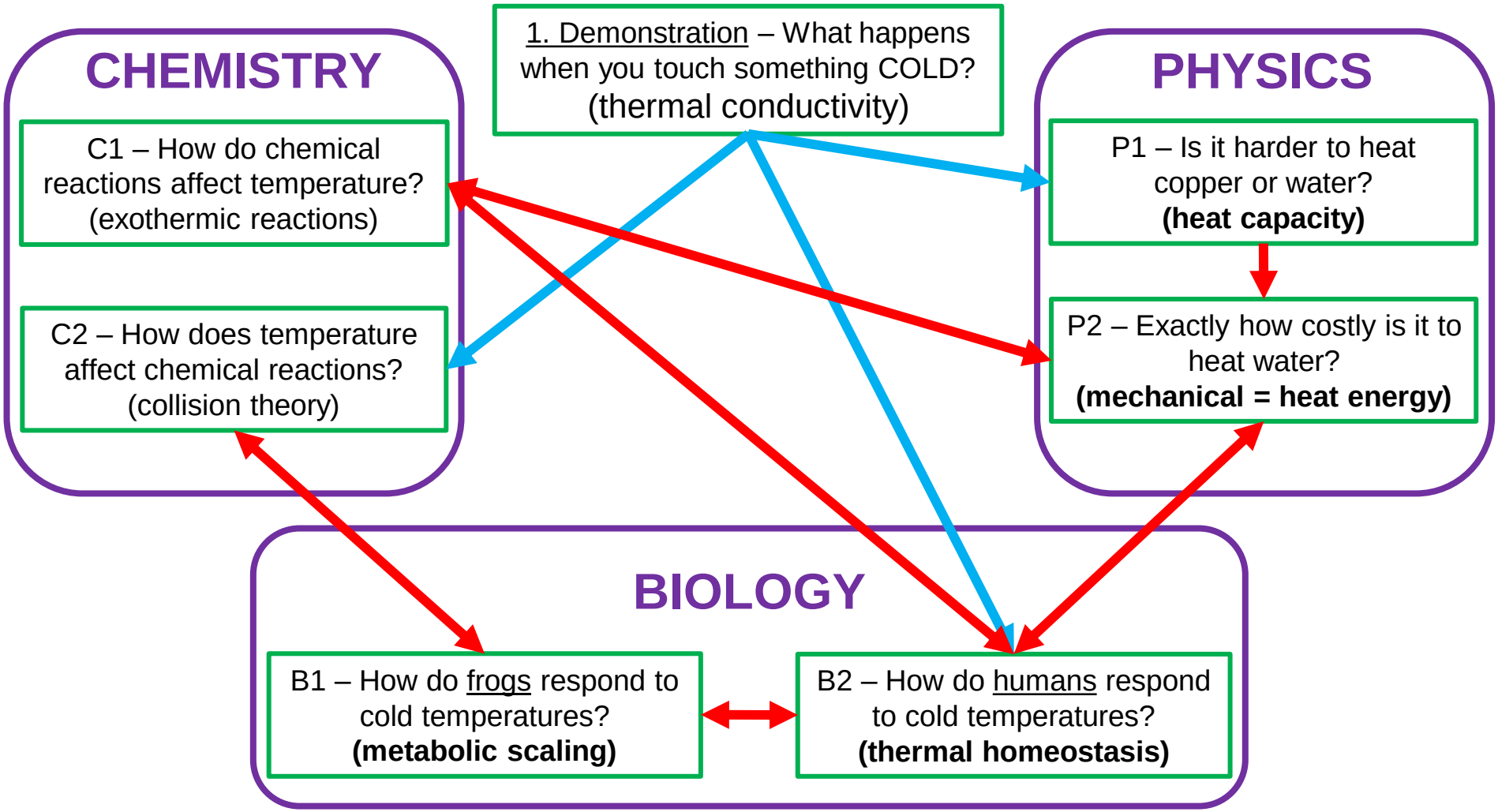
Dr. Raffel's (2019) homemade Joule apparatus



James Joule's (1843) "water friction" apparatus

PUB Activity – Experimental Plan

- Two experiments per team
- Every experiment connects to AT LEAST one other experiment



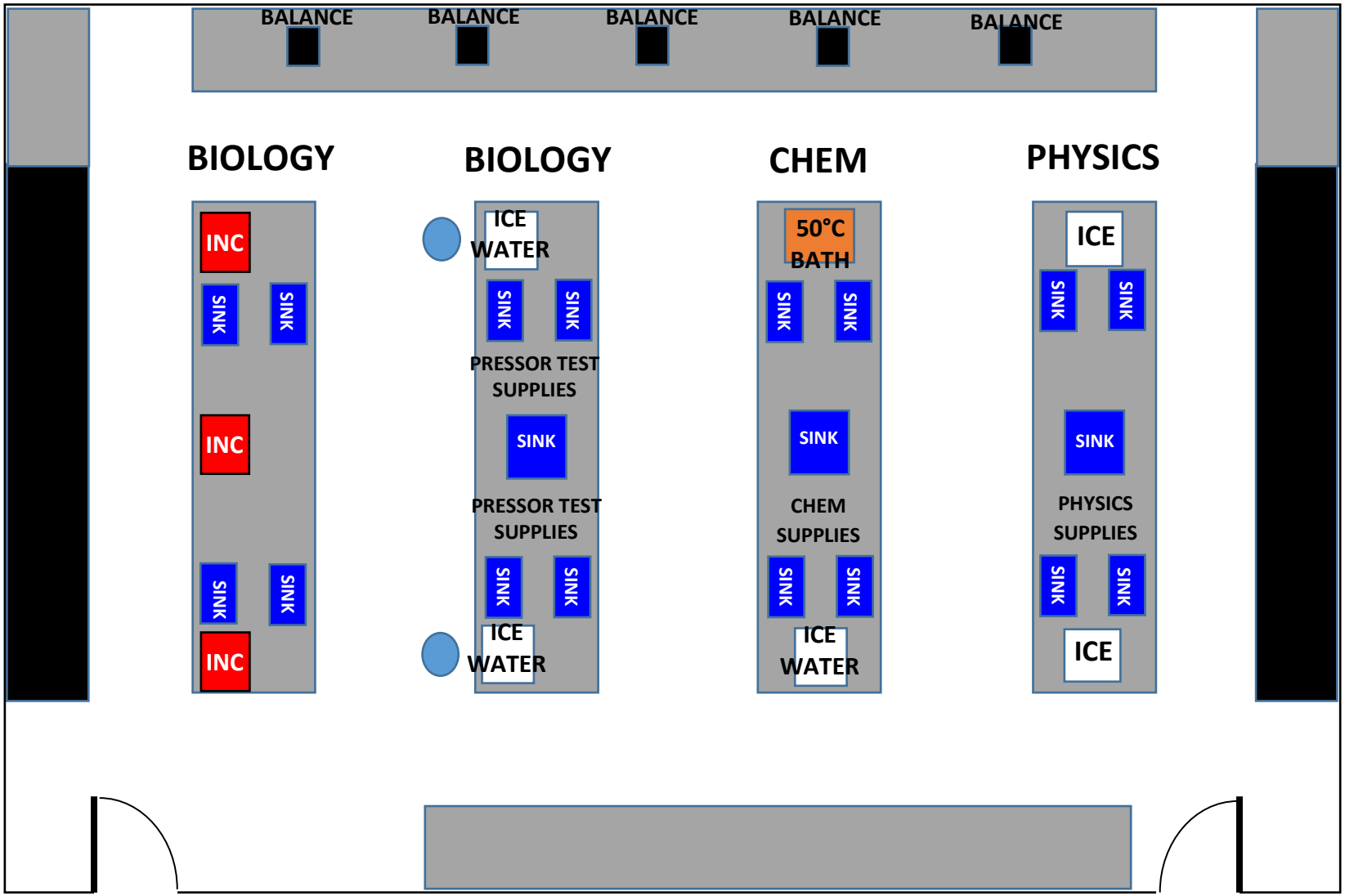
Hypothesis development

Groups:

- Write a hypothesis statement on your white board that answers one of the following questions:

1. **(BIO) How will temperature affect a frog's breathing rate, and why?**
2. **(CHEM) How will temperature affect a chemical reaction rate, and why?**
3. **(PHYSICS) Will it take more energy to heat copper or water, and why?**

Lab Setup Notes



Physics FOLLOW-UP

(After groups have completed one experiment)

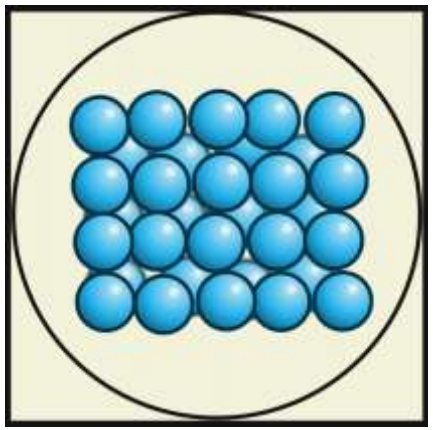
Questions:

1. Why does it take so much energy to heat up water?
2. How are different types of energy related to each other?

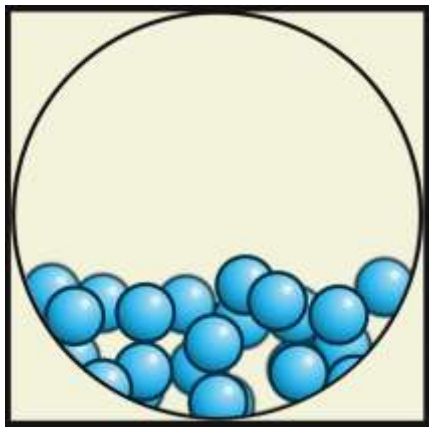
1. Why does it take so much energy to heat water?

- Molecules move differently in different substances:

COPPER



WATER



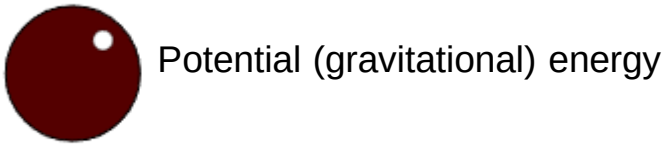
- Water molecules STICK TOGETHER in a weird way
  - Hydrogen bonds – opposite **electric** charges in H & O stick together
  - To heat water, you first need to BREAK the hydrogen bonds between water molecules.
  - Most of the energy you add goes into increasing **electrical potential energy**, rather than increasing molecular movement (heat)!

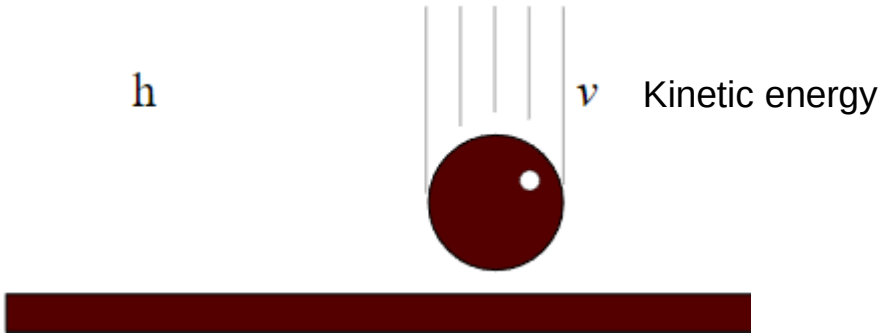
2. How are different types of energy related?

- Two broad categories of ENERGY types:

  - **Kinetic Energy:**
    - ➢ **Mechanical energy**
    - ➢ Sound energy
    - ➢ **Heat energy**

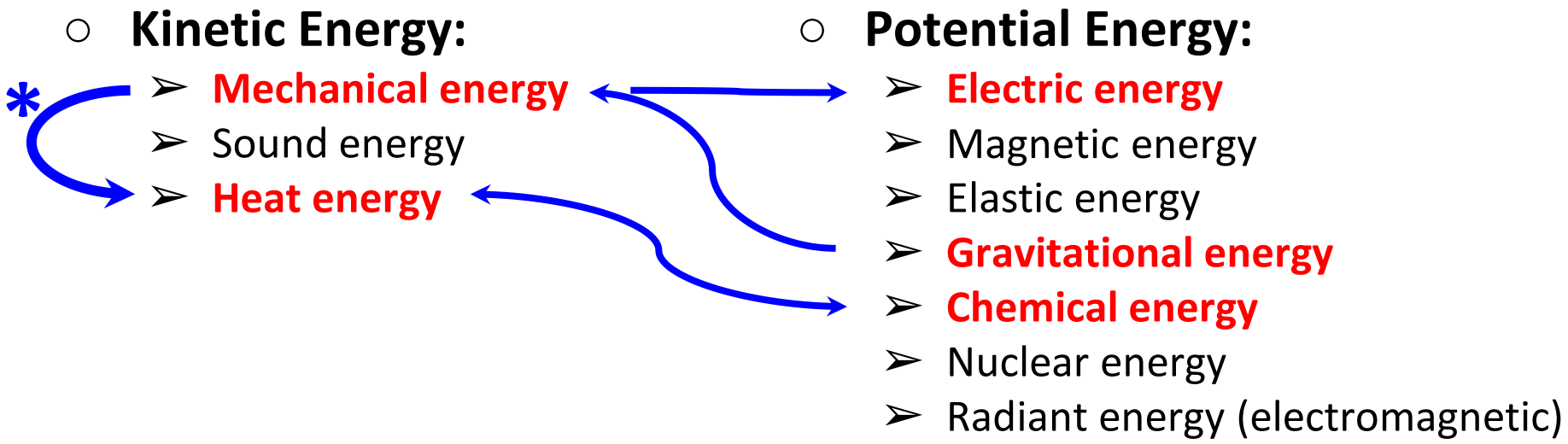
  - **Potential Energy:**
    - ➢ **Electric energy**
    - ➢ Magnetic energy
    - ➢ Elastic energy
    - ➢ **Gravitational energy**
    - ➢ **Chemical energy**
    - ➢ Nuclear energy
    - ➢ Radiant energy (electromagnetic)





2. How are different types of energy related?

- LOTS, but they come in two broad categories:



1st Law of Thermodynamics

- Energy cannot be created or destroyed, but it CAN transition from one <u>form</u> into another

2. How are different types of energy related?

- **Joule apparatus**

Gravitational potential energy (of the weight) → **Heat energy lost when the weight hits the floor**

↓

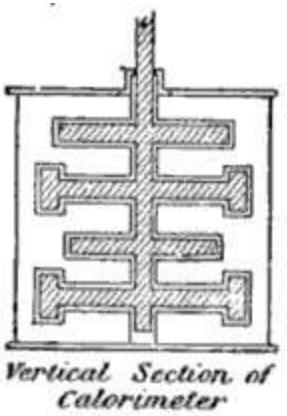
Kinetic energy (paddle spinning) → **Heat energy lost to friction in the gears**

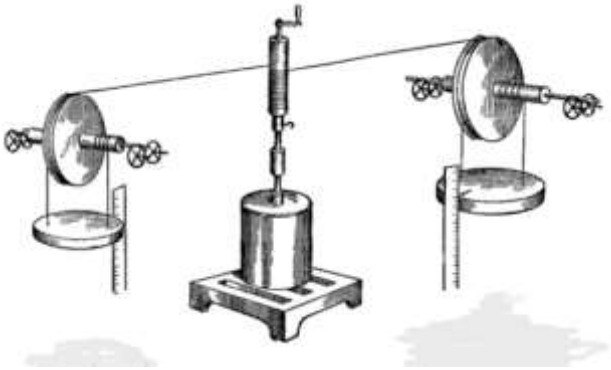
↓

Kinetic energy (water molecules) → **Heat energy lost through the insulated container walls**

↓

Heat energy (in the water) → **(Experimental error)**





Chemistry FOLLOW-UP

(after groups have run some tests)

Questions:

- **Why does temperature affect chemical reaction rates?**
- **How much energy is released by H_2O_2 decomposition?**

Collision Theory for Chemical Reactions:

- Small molecules only react with each other if they COLLIDE with enough SPEED (kinetic energy) to stick together
  - **Activation Energy** (E_A) - minimum energy for reaction

Slow crash (bounce)

Fast & precise (stick)

Collision Theory for Chemical Reactions:

- Small molecules only react with each other if they COLLIDE with enough SPEED (kinetic energy) to stick together
  - **Activation Energy** (E_A) - minimum energy for reaction

But what about CATABOLIC (decomposition) reactions?

(like $H_2O_2 \rightarrow H_2O + O_2$)

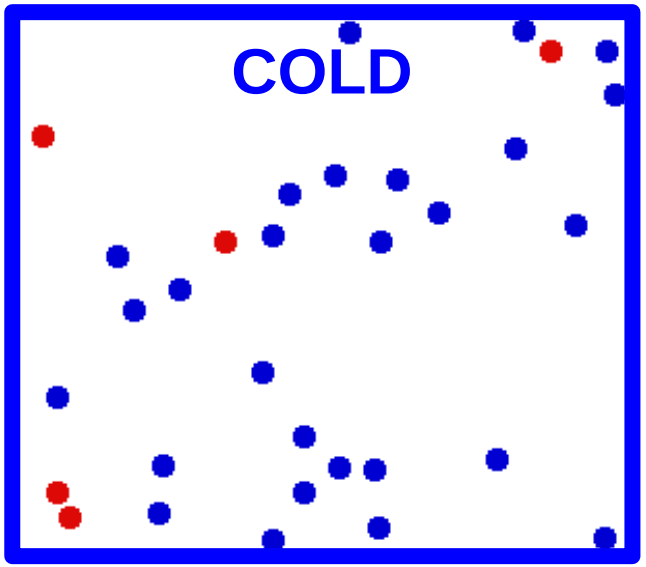
- **Big molecules need kinetic energy to make them BREAK APART.**

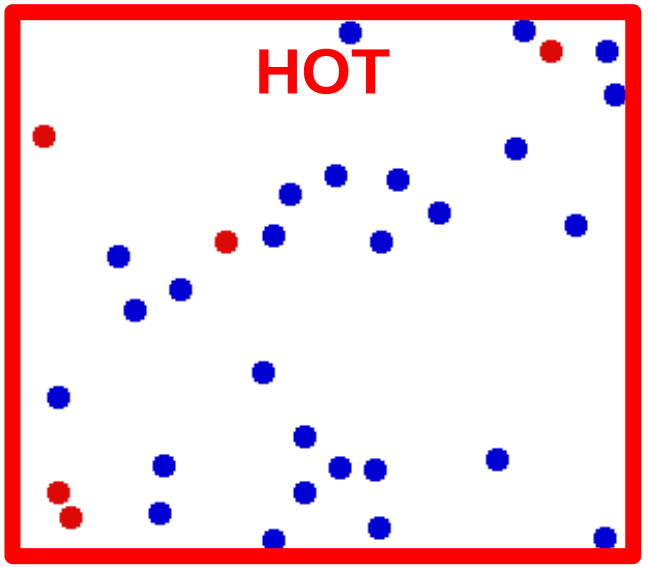
Collision Theory for Chemical Reactions:

- Small molecules only react with each other if they COLLIDE with enough SPEED (kinetic energy) to stick together
  - **Activation Energy** (E_A) - minimum energy for reaction

Why is temperature so important?

➢ **Because Heat = Kinetic Energy!**

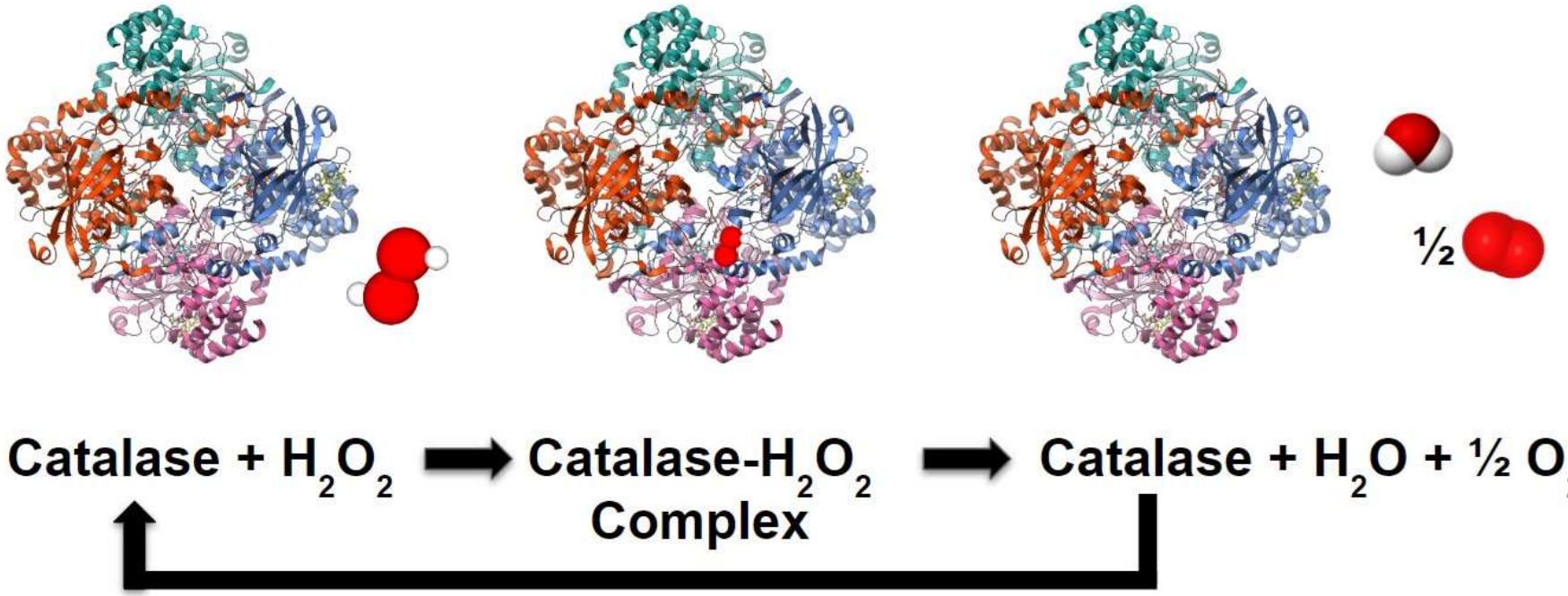




Catalase Enzyme

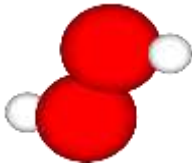
- Binds to hydrogen peroxide
- Stabilizes the “transitional state”

➢ Lowers the **Activation Energy** and speeds up the reaction



Chemical Bond Energy:

- **Potential energy stored in chemical bonds ("Enthalpy of formation")**



H_2O_2

hydrogen peroxide (aqueous)

H_2O

water (liquid)

½ O_2

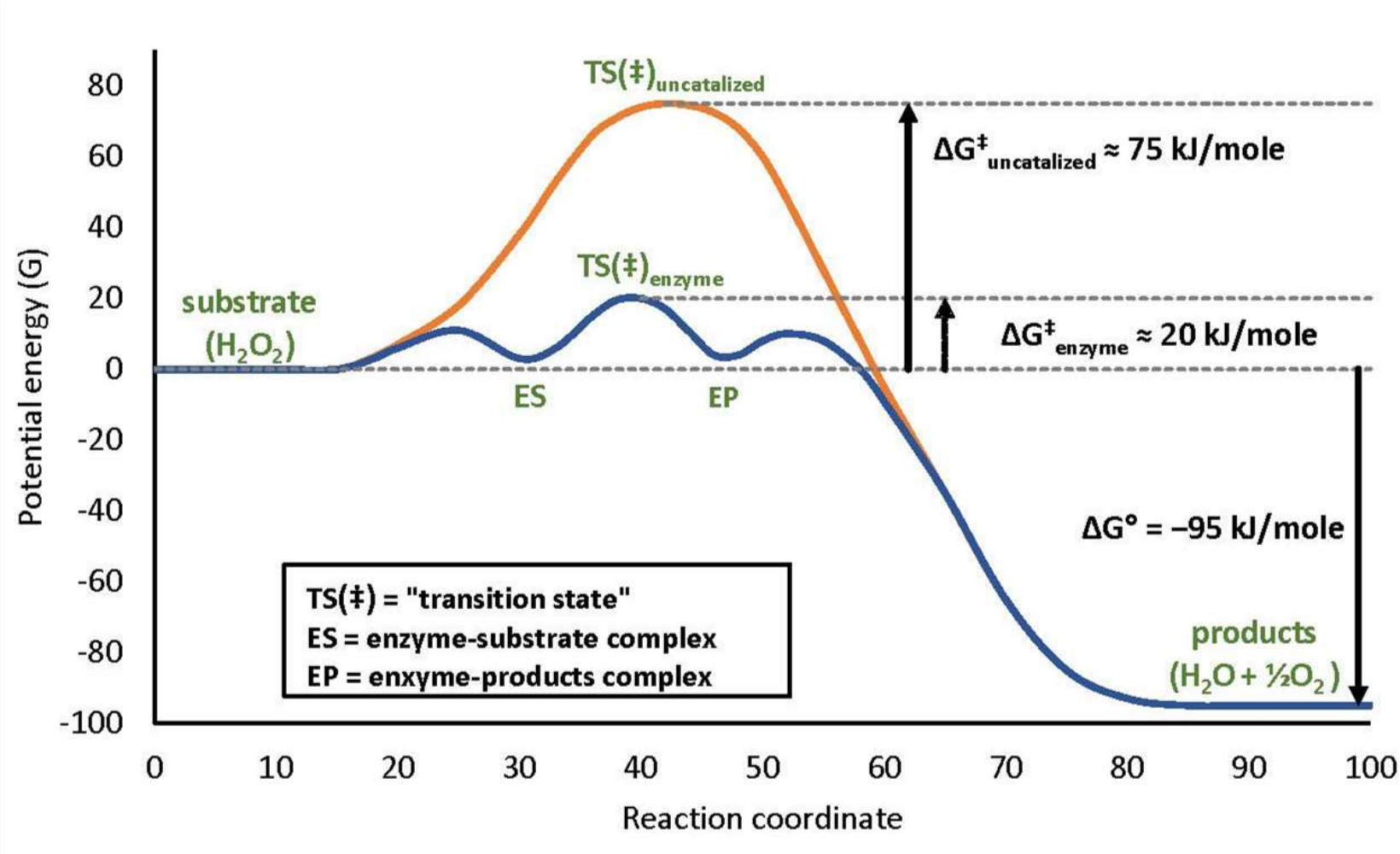
oxygen (gas)

ΔH:	−191 kJ/mole	−286 kJ/mole	0 kJ/mole

Question:

1. How much did the total chemical bond energy DECREASE during this chemical reaction?
2. Where did the "lost" energy go?

Transition State Theory:



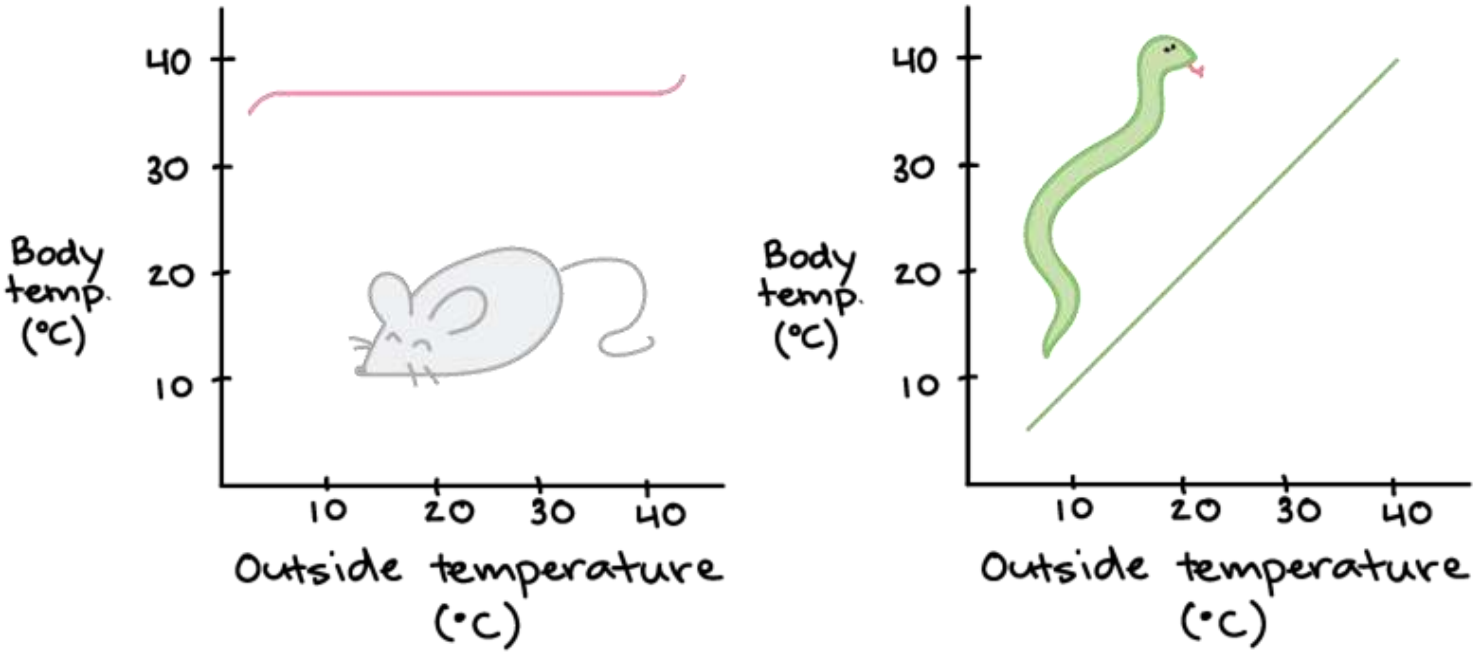
Biology FOLLOW-UP

(after at least one group finishes each experiment)

Questions:

- **How do frogs and humans differ in their responses to external temperature?**
- **What are the costs and benefits of being warm- or cold-blooded?**

Warm-blooded versus Cold-blooded:



Question:

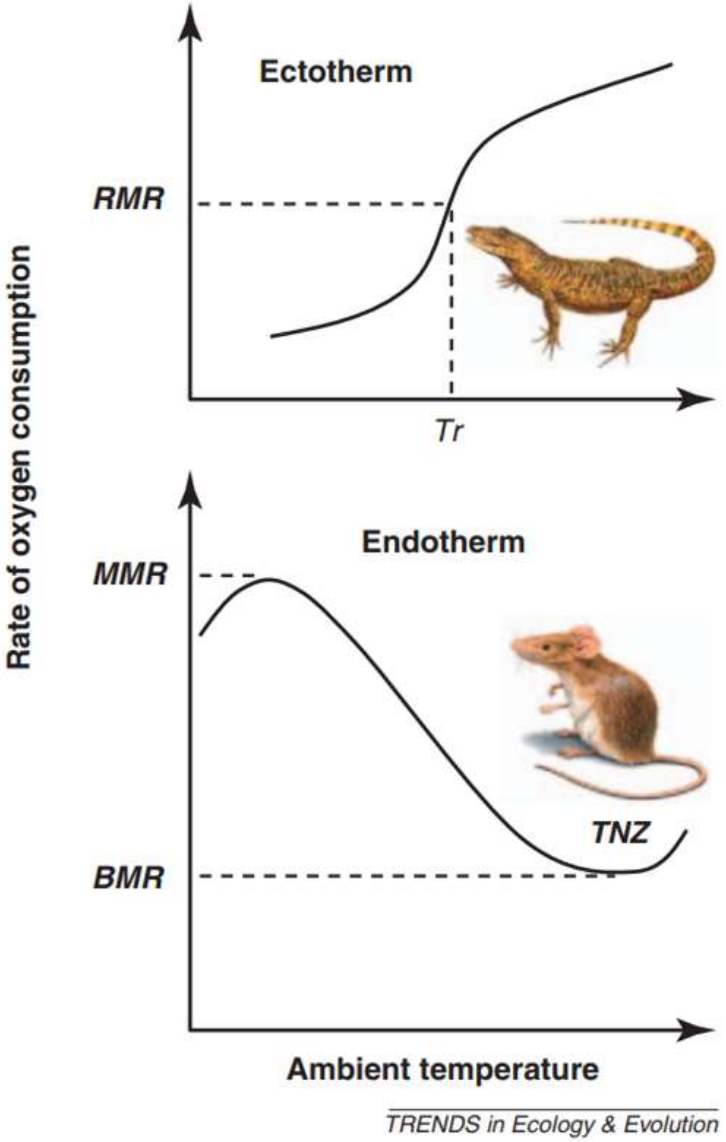
- Based on your experiments, what are some key similarities and differences in endotherm versus ectotherm metabolic responses to temperature?

Warm-blooded versus Cold-blooded:

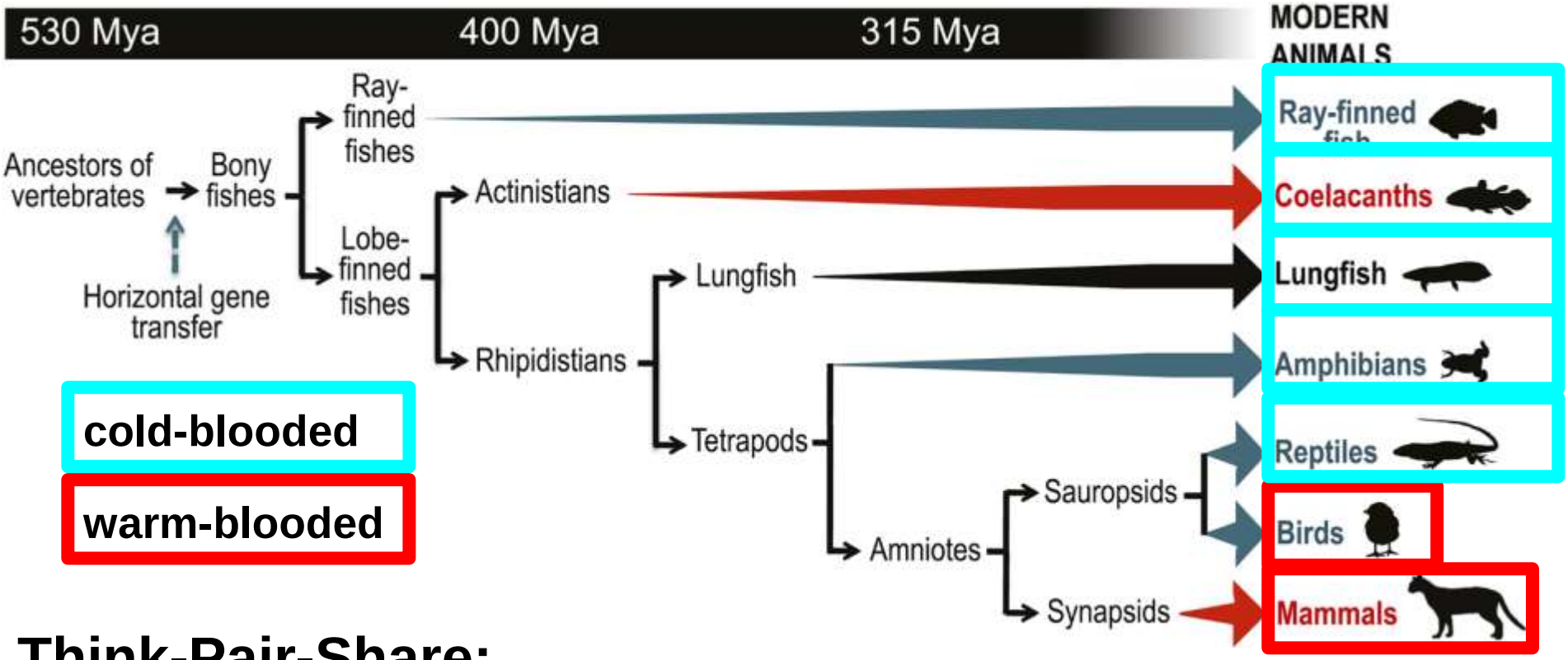
Think-Pair-Share:

1. Endotherms and ectotherms have OPPOSITE metabolic responses to temperature. Why do you think this happens?

2. Is endothermy a BETTER thermal strategy than ectothermy? Why or why not?



Evolutionary Thermal Biology



Think-Pair-Share:

1. Humans and frogs diverged ~320 million years ago. **Was our last common ancestor probably warm-blooded or cold-blooded? Why?**
2. **Do you think the last common ancestor of birds and mammals was warm-blooded? Why or why not?**

Warm-blooded versus Cold-blooded:

Pros & Cons of Endothermy:

PROS:

- Warm-blooded animals can remain active in cold environments (or at night).
- Warm-blooded animals may be FASTER than cold-blooded animals, at least in cold environments.

CONS:

- **ENERGETICALLY COSTLY**: Warm-blooded animals need a LOT of food to maintain high body temperatures and high metabolic rates.
- Cold-blooded animals can survive long periods without food!