What are heat and temperature?

A Historical Analysis

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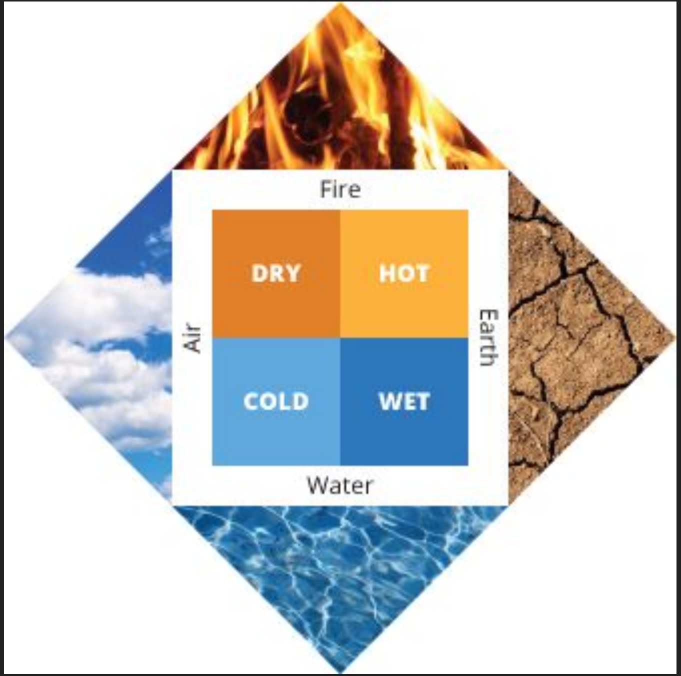
Development

2

Two Eras:
Pre-quantification
and
post-quantification

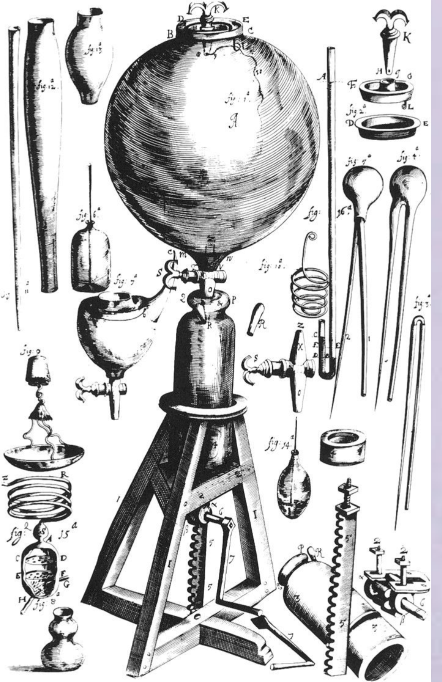
Pre-quantification ideas

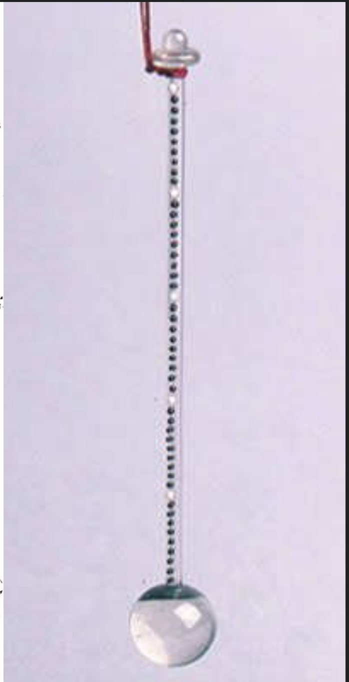
- The ancient notion of temperature was an **amorphous**, fundamentally relative property
  - The same weather can be hot or cold, but never absolute
- Aristotle’s properties and elements
- 1612 thermometer allowed **quantified** measurements



Volume, Temperature, and Pressure

- Using an air pump in 1656, Robert Boyle and Robert Hooke **noticed** that the product of pressure and volume was constant
- When the thermometer was **invented**, Gay-Lussac noticed a relationship between pressure and temperature





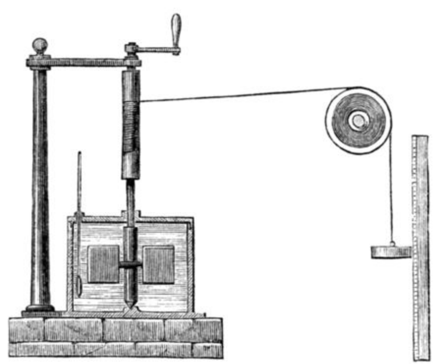
Ideal Gas Law: $PV = nRT$

Boyle’s Law	Pressure and volume are inversely related
Charles's Law	Temperature and volume are directly related
Gay-Lussac’s Law	Temperature and pressure are directly related

- Discoveries led to holistic model: Ideal Gas Law
- Model allowed quantification + optimization of steam engines
- Model **generalized** to a broader domain and inspired deeper insights

Mechanical Equivalent of Heat

- Scientists understood that pressure (kinematics) and temperature were related.
- Sadi Carnot, in describing engine efficiency, defined (useful) work as an engine's ability to lift a specific weight (force) over a certain distance (height).
  - This unit was in *lbs over a foot*, the imperial equivalent of *newton meters* (aka *Joules*).
- Joule experimentally demonstrated that a given amount of work would always produce a certain amount of heat.



The new famous **Joule Apparatus.**

The First Law of Thermodynamics

- The First Law of Thermodynamics is a generalization of the Mechanical Equivalent of Heat.
- **Mechanical Equivalent of Heat** states that a specific amount of *heat can be exchanged* for a specific amount of work (and vice versa).
- **Conservation of energy** generally states that the *total energy* within an isolated system *is constant*.
- **The First Law of Thermodynamics** further generalizes the two prior laws, stating that the change in energy of a system is equal to the change in thermal energy minus the work done by the system.
- All of this was possible because we measured a constant **relationship** between two **different** concepts.

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External Effects

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Exploring Other Forms Of Energy

- While early research into thermodynamics focused on kinematic and thermal energy, the laws of thermodynamics were generalized to many other forms of energy.
- For example, the movement of magnetic fields was found to induce a current in a wire and vice versa.
- Leveraging the thermodynamic model that various forms of energy can be converted into one another in a (theoretically) lossless manner, scientists were able to establish an equivalence between electrical energy and mechanical energy.

Conservation of Momentum

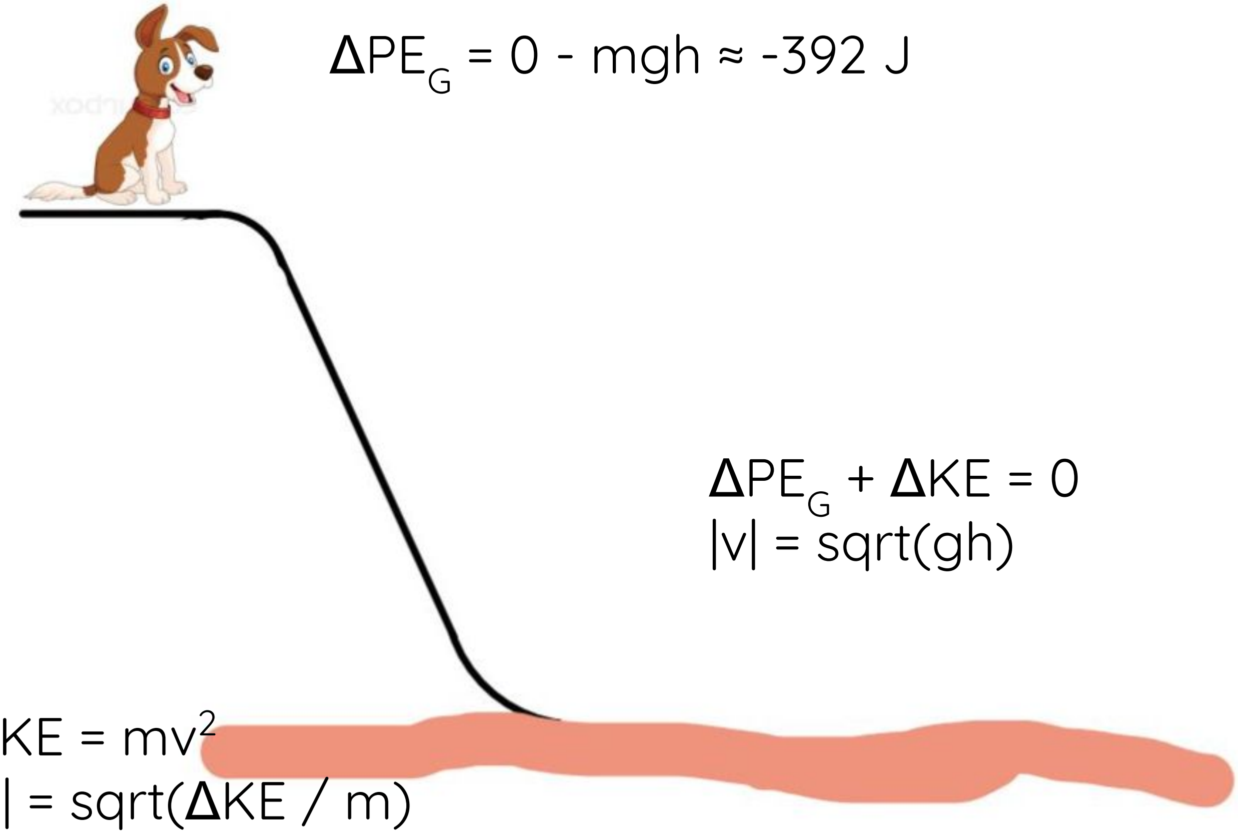
- Newtonian laws preceded the discovery of Thermodynamics.
- Using Newton's third law of physics (every action has an equal but opposite reaction), physicists discovered the conservation of momentum.
- While related, momentum and energy are different concepts.
- At first, scientists thought that the conservation of momentum also meant that energy was conserved.
- However, with the discovery of the 1st law of Thermodynamics, physicists identified two types of collisions: inelastic collisions and elastic collisions.
  - Elastic collisions are collisions that conserve energy.
  - Inelastic collisions cause a maximum loss of energy.
  - Both conserve momentum.

Reinterpretation of Kinematics

- Since work had a definition grounded in Physics, useful formulae could be derived to link the kinematic world with the Thermodynamic world.

$$\Delta PE_g = mg\Delta h \qquad \Delta KE = mv^2$$

- From there, physicists could analyze kinematic problems energetically: Scrappy (m = 4 kg) descends a frictionless slide of height 8 meters [...]. How fast was Scrappy moving when they reached the bottom of the slide?



$\Delta PE_G = 0 - mgh \approx -392\text{ J}$

Drawing not to Scale

$\Delta PE_G + \Delta KE = 0$

$|v| = \text{sqrt}(gh)$

$\Delta KE = mv^2$

$|v| = \text{sqrt}(\Delta KE / m)$

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The Synthesis Cycle

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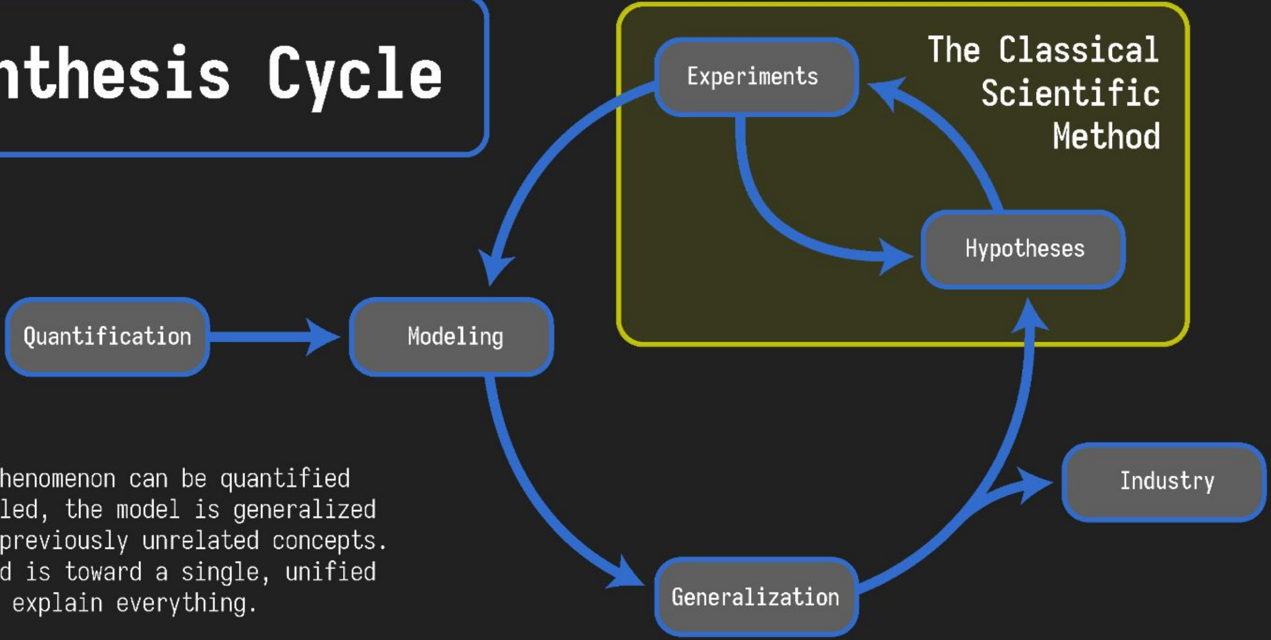
The Synthesis Cycle



Once a phenomenon can be quantified and modeled, the model is generalized to link previously unrelated concepts. The trend is toward a single, unified model to explain everything.

Images Used

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