Michigan Science Olympiad Thermodynamics

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Scoring

- Two Overall Components
  - Insulating device demonstration
  - Written Test

- Scoring
  - Written Test – 45 points
  - Insulating Device - 55 Points
    - Plot / Chart Score – 10 points
    - Prediction Score – **25** Points max
    - Heat Retention Score – **20 Points**
  - **TOTAL** **100 Points**
  - Penalties
    - Competition rule violation
    - Construction rule violation

Part 1:
Insulated Device Demonstration

SCIENCE OLYMPIAD
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Event: What to Bring

- Students **must** bring:
  - Insulating device
  - One - 250 mL beaker
  - Splash proof eye protection
  - Plots (<u>need to submit at impound for scoring</u>)
  - Writing utensils

- Students **may** Bring:
  - Up to two calculators
  - Reference material in one 3-ring binder
  - Parts, supplies, tools, thermal probe
- 2 students per team allowed

Impound: On the Day of the Event

- Impound is required for:
  - Insulating device
  - Parts, supplies, tools
  - Beaker
  - Plots: One set not to be returned and not available for the competition time

- Not Required to be Impounded
  - Eye Protection
  - Calculator
  - Reference material / notes
  - Plots: Duplicate copy for prediction part of the competition

Insulating Device: Requirements

- Designed, built, and calibrated before the competition
- Div. C : 15.0x15.0x15.0 cm cube,
- Div. B : 20.0x20.0x20.0 cm cube
- Passive design without any electrical components, chemical reactions or other energy sources
- Contain a removable **standard** 250 mL beaker
  - Unmodified beaker
  - Beaker can be glass or plastic
- Device must have a **hole in top** for insertion of the temperature probe
  - 0.5 inch hole diameter,
  - Must be **less than 12 cm** from the inside bottom of the beaker to the top of the hole
  - Hole that can be plugged by a cotton ball provided by the event supervisor

Insulating Device: Construction Materials

- Almost any type of raw material can be used for construction:
  - Wood (Sawdust is OK), Paper, Cardboard,
  - Plastic, Aluminum Foil, Metal
  - Natural or man made materials – wool, cloth, feathers
  - Bubble Wrap

- Materials not allowed in the construction of insulating device:
  - Fiberglass, asbestos, mineral wool
  - Commercially available thermos/cooler/vacuum sealed devices
  - Materials that generate heat or other types of energy sources

- **Check www.soinc.org for updates**

Insulating Device Tips

- **Consider the methods for heat transfer**
  - Conduction
  - Convection
  - Radiation
  - Evaporation

- **Consider the heat flow**
  - What are the steps to heat transfer
  - Limit internal convection via small air spaces
  - Look up R values of materials: wikipedia.org/wiki/R-value_(insulation)

- **Consider Reliability**
  - Water vapor can destroy cardboard and some other materials after a few tests
  - Solid / sturdy construction will help with repeated testing
  - Must support the weight of the water
  - Must be able to assemble and disassemble for inspection

- Material Resources
  - Balsa Wood www.lonestar-balsa.com
  - Free sawdust from Lowe's, Home Depot
  - Craft store

Plots and Graphics

- Provide up to 4 temperature verses time plots (for scoring)
  - Demonstrate the performance of the device for various starting temperatures and quantities of water.
  - The plots can possibly be on a single XY graph, or, up to 4 separate XY graphs on one, or multiple sheets of paper

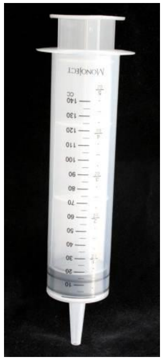
- Scoring
  - 2 points for including data spanning at least one variable range (initial temperature or water volume)
  - 2 points for including at least 10 data points per curve
  - 2 points for proper labeling (e.g. title, axis label, team name, units)
  - 0.5 points for each graph or table turned in (up to 2 points total)
  - 2 points for including a labeled **device picture or diagram**
  - More than 4 curves can be provided, but, they will not add to the teams score

- Total of 10 **"Easy Points"**

Test Conditions

- The ambient air temperature around the insulated device will be the room temperature
- Water bath between **60 to 75 °C**,
  - Water bath temperature will be maintained to be the same for all teams
  - Water bath
    - Hotplate with magnetic stirrer to keep bath water temperature uniform
    - Hot water in a small coffee pot to quickly adjust the bath temperature
    - More water = More stable temperature

- Volume of Water
  - **100mL at Regional**
  - 75, 100 or 125 mL State
  - 75, 80, 85, 90, … 120, 125mL for National
  - 140 ml catheter tip syringe for water fill



- 1 beaker inserted into the device

Cooling Time and Temperature Measurement

- Cooling time
  - **Division B: 25 minutes**
  - **Division C: 20 to 30 minutes**
  - Same cooling time for all teams
  - Event supervisor will measure final temperature at the end of the cooling period

- Temperature will be measured using a thermometer or temperature probe
  - Thermocouple based measurement is quicker and has better resolution
  - Measure temperature close to the bottom of the beaker

Insulated Device Demonstration

- Teams will be given about 5 minutes to setup / prepare devices
- Teams will have water placed in their device in sequence
- Teams close, secure their device
- Teams may measure the starting water temperature with their own thermometer **(temperature prediction is 25 points)**
- Teams must provide ending water temperature prior to starting the written test **3 to 5 minutes max**
  - Teams may use duplicate plots / notes to predict the final temperature

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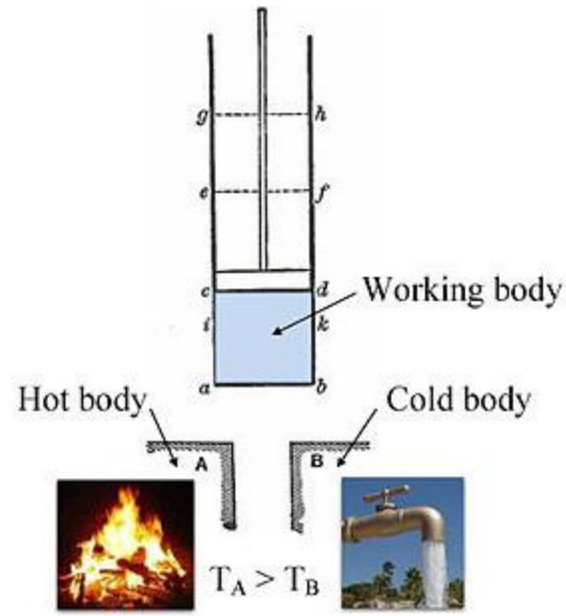
Part 2:
Written Test

Binder

- 3 Ring Binder (nothing can fall out)
  - “Cheat Sheet”
  - Constants
  - Equations
  - Detailed sections
  - Definitions and terminology
    - Temperature conversion
    - Heat units
    - Thermal conductivity
    - Heat capacity
    - Specific heat
    - Laws of thermodynamics
    - History of thermodynamics
    - Thermodynamic processes
- Graphs / tables / diagrams

Part II: Written Test

- Written test will occur after all teams have been loaded with water
- All teams will have the same time for the Written Test (minimum of 20 minutes)
- Test will consist of at least (**3**) questions from each of the following areas
  - History of Thermodynamics
  - Definition of Temperature, Temperature scales, conversions, and definitions of heat units
  - Kinds of heat transfer, thermal conductivity, heat capacity, specific heat
  - Phases of matter, phase transitions, phase diagrams, latent heat, ideal gas law
  - Thermodynamic laws and processes (e.g. Carnot cycle, efficiency, adiabatic, isothermal
  - Division C only: Radiant exitance, entropy, enthalpy



Annotated color version of the original 1824 Carnot heat engine showing the hot body (boiler), working body (system, steam), and cold body (water), the letters labeled according to the stopping points in Carnot cycle.

https://en.wikipedia.org/wiki/Thermodynamics

Thermodynamics: you probably use it every day

- Thermodynamics intentionally separates the observational space in "**system**" and "**surrounding**" and is primarily concerned about the transformation of energy from **heat** to **work** (and vice versa) and its transfer across the "**boundary**" that separates the system from the surroundings

- In its formulations, Thermodynamics does not introduce the variable of **time – **that is the domain of **heat transfer**

- Zeroth Law
  - The Zeroth Law simply says there is no heat flow between objects that are the same temperature.
  - The zeroth law enables us to use thermometers to compare the temperatures of any objects we like.

Thermodynamics: you probably use it every day

- First Law
  - Conservation of Energy
  - Energy cannot be created or destroyed. It can only change form or be transferred from one object to another.
  - Driving in a car
  - The conservation of energy principle defined by the first law of thermodynamics says that when all of the fuel's energy is released by burning in the engine's cylinders it doesn't disappear. The total quantity of energy stays the same and must be accounted for. In the case of the gas engine it either becomes thermal energy (heat) or mechanical energy (work). For every 100 units of fuel energy that is burned in the engine a hundred units of converted energy has to end up somewhere.

Thermodynamics: you probably use it every day

- Second Law
  - Heat flows spontaneously from a body at a higher temperature to a body at a lower temperature and does not flow spontaneously in the other direction.
  - It is impossible to convert all the thermal energy from a heat source to work without discarding some thermal energy to a heat sink
  - The degree of randomness or disorder in a system is called its **entropy**.

  - For the good – the soup is too hot
  - For the bad – it's too cold outside
  - Everything you do

- One implication of the second law of thermodynamics is that in order for a process to happen, it must somehow increase the entropy of the universe (disorder).
- Well, entropy is a measure of disorder in the universe. An object or substance with high entropy is highly disordered. When you put things in order, such as, putting your child's toys away in a box, you're decreasing entropy. Unfortunately, you're also producing entropy through the heat in your muscles. In fact, entropy in the universe can only increase. It can never decrease.

Thermodynamics: you probably use it every day

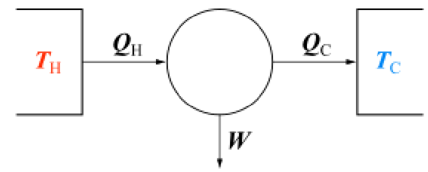
- Third Law
  - The third law of thermodynamics says that the entropy of a perfect crystal at absolute zero is exactly equal to zero.
  - It is impossible for any process, no matter how idealized, to reduce the entropy of a system to its absolute-zero value in a finite number of operations.
  - Not so much
  - You cant get a 100% efficiency machine

Carnot Engine and Cycles

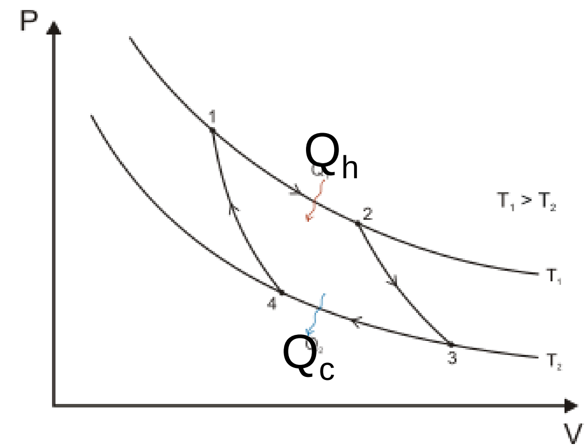
- A heat engine acts by transferring energy from a warm region to a cool region of space and, in the process, converting some of that energy to mechanical work. Second law places upper limit on this conversion
  - Internal combustion engine (gasoline, diesel, gas turbine)
  - External combustion engines (steam engines, central electrical power stations)

- A heat pump is opposite to a heat engine in the sense that it takes work as input and transfers thermal energy from lower temperature to a higher temperature
  - Refrigerator
  - Air Conditioner
  - Heat pump (not so common in Michigan)

- A Carnot heat engine is an ideal heat engine that operates on the reversible Carnot cycle, developed by Nicolas Léonard Sadi Carnot in 1824. It consists of four processes (or steps)
  - 1-2: Heat addition at constant temperature (Q_h, hot)
  - 2-3: Reversible, ideal, constant entropy expansion (Work out)
  - 3-4: Heat rejection at constant temperature (Q_c, cold)
  - 4-1: Reversible, ideal, constant entropy compression (Work in)
  - The Carnot cycle plotted on a pressure-volume axes is shown here



Carnot engine diagram (modern) - where an amount of heat Q_H flows from a high temperature T_H furnace through the fluid of the "working body" (working substance) and the remaining heat Q_C flows into the cold sink T_C, thus forcing the working substance to do mechanical work W on the surroundings, via cycles of contractions and expansions.



Thermodynamic Terms

- Thermal Conductivity: is the property of a material to conduct heat (W/(m-K)). Thermal energy transfer in unit time, across a body of unit cross-section area, of unit thickness, with a unit temperature difference across its thickness
- Heat Capacity: ratio of the heat added to (or removed from) an object to the resulting temperature change (J/K) – less commonly used in practice

$$C = \frac{Q}{\Delta T}$$

- Specific Heat: heat required to raise the temperature of unit mass of a given substance by one unit of temperature (J/kg-K)
- Latent Heat: energy released or absorbed, by a body or thermodynamic system, during a constant-temperature process (typically during a phase change process such as during boiling or freezing)

$$L = \frac{Q}{m}$$

- Phases of Matter: one of the distinct forms in which matter can exist. Three states of matter are observable in everyday life are: solid, liquid, gas. The fourth state of matter "plasma", though the most frequent form of matter in the universe, is found on earth in fluorescent lamps, neon signs, welding arcs, lighting, etc.

Material	Thermal conductivity [$W \cdot m^{-1} \cdot K^{-1}$]
Acrylic glass (Plexiglas V045i)	0.170[2]–0.200[3]
Alcohols, oils	0.100[4][5]
Aluminium	237[6]
Copper (pure)	401[4][7][8]
Diamond	1,000[4]
Fiberglass or foam-glass	0.045[5]
Polyurethane foam	0.020–0.021[4]
Expanded polystyrene	0.033–0.046[9]
Manganese	7.810[4]
Water	0.591[10]
Marble	2.070–2.940[4][11]
Silica aerogel	0.020[4]
Snow (dry)	0.050[4]–0.250[4]
Teflon	0.250[4]

Thermodynamic Terms (cont.)

- Heat: Amount of energy flowing from one body of matter to another spontaneously due to their temperature difference, or by any means other than through work or the transfer of matter (J)
- Work: Energy transferred by the system to its surroundings due to forces exerted by system on its surroundings (J)
- Energy: property that must be transferred to an object in order to perform work on, or to heat, the object (J)
- Power: rate of doing work, the amount of energy transferred per unit time. (W)
- Temperature: A measure of the average kinetic energy of constituent particles of matter. It's a physical quantity that expresses the subjective perceptions of hot and cold on intensity of heat present (K or ^{0}C).
- Enthalpy: equivalent to the total heat content of a system. It is equal to the internal energy of the system plus the product of pressure and volume
- Entropy: the unavailability of a system's thermal energy for conversion into mechanical work, often interpreted as the degree of disorder or randomness in the system
- Absolute Zero: lowest temperature that is theoretically possible, at which the motion (kinetic energy) of the particles that constitutes matter would be zero. Zero (0) K, -273.15 ^{0}C, or -459.67 ^{0} F

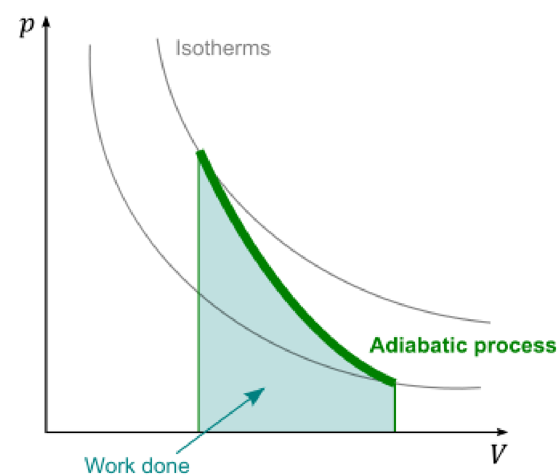
    Celsius (°C)= K - 273.15

Isothermal and Adiabatic Processes

- Isothermal is a change of a system state while the temperature remains constant (ΔT = 0)
- Adiabatic process occurs without transfer of heat or matter; energy is transferred to its surrounds only as work
  - Adiabatic heating occurs when pressure is increased (see piston)
  - Adiabatic cooling occurs when pressure is decreased (air conditioner coils)

https://en.wikipedia.org/wiki/Adiabatic_process

- Reversible process is an ideal process whose direction can be "reversed" by inducing infinitesimal changes to some property of the system via its surroundings, with no increase in entropy



For a simple substance, during an adiabatic process in which the volume increases, the internal energy of the working substance must decrease

https://en.wikipedia.org/wiki/Thermal_efficiency

History of Thermodynamics

- 1650-Otto von Guericke built the world's first vacuum pump
- 1656-English physicist and chemist Robert Boyle and English scientist Robert Hooke built an air pump
- 1824-French physicist Nicolas Léonard Sadi Carnot who believed that engine efficiency was the key that could help France win the Napoleonic Wars
- 1854-Scottish physicist Lord Kelvin was the first to formulate a concise definition of thermodynamics

https://en.wikipedia.org/wiki/Thermodynamics

Suggested References

- Websites:
  - Soinc.org Thermodynamics Event pages
  - Scioly.org student forums / wiki / test exchange
  - Wikipedia (Star evolution, spectral classification, radio astronomy, etc.)

https://www.soinc.org/thermodynamics-b and https://www.soinc.org/thermodynamics-bc
https://store.soinc.org/us/Digital-Test-Packets/c/2723?resetallfilter=1
https://www.soinc.org/sites/default/files/example%20keep%20the%20heat%20-%20thermodynamics%20plots%20111008.pdf
http://en.wikipedia.org/wiki/Thermodynamics
http://www.ohio.edu/mechanical/thermo/
http://scienceworld.wolfram.com/physics/topics/Thermodynamics.html
http://www.khanacademy.org/video/thermodynamics--part-1?playlist=Physics