

13: Heat and Thermodynamics

Key Physics Terms	Variables Used and Their Metric Units
<ul style="list-style-type: none"> Thermodynamics: The study of processes in which energy is transformed as work or heat. Temperature: A measure of the average kinetic energy of the particles. The higher the temperature the faster the molecules move. Linear Expansion: A change in length of a solid due to a temperature change. Proportional to the linear expansion coefficient, α, for the material. Volume Expansion: A change in volume of a solid due to a temperature change. Proportional to the volume expansion coefficient, β, for the material. Note $\beta = 3\alpha$. Energy: The ability to do work or supply heat. System: The object or objects being studied. Surroundings: Everything surrounding the system. Internal Energy: The total energy of all the molecules in the system. Heat: The transfer of energy from one object to another due to a difference in temperature. Work: In thermodynamics the work done by the system is positive; the work done on the system is negative. Calories: The amount of heat required to raise the temperature of 1g of water by 1°C. 1 calorie = 4.18 Joules. State Functions: Quantity which is dependent only on the current state of the system not the path taken to reach that state, e.g. Temperature. Specific Heat Capacity: The amount of energy required to change a unit mass of a substance by 1°C. Heat Capacity: The amount of heat needed to raise a mass of a substance, given by the product of mass and specific heat capacity. Endothermic reactions: A reaction in which energy is absorbed into the system from the surroundings. Exothermic reactions: A reaction in which energy is released from the system into the surroundings. Calorimetry: A quantitative measurement of energy lost/gained from the system, which is equal & opposite to that lost/gained from the surroundings. Latent Heat: The energy required to change the phase of a substance, without changing the temperature of the substance. Heat of fusion: The heat required to change 1kg of a substance from a solid to a liquid state, which is equal to the heat lost when the liquid changes to a solid state. Heat of vaporization: The heat required to change 1kg of a substance from a liquid to a vapor phase, which is equal to the heat lost when the vapor changes to a liquid phase. Thermal Equilibrium: Two objects in thermal contact cease to exchange net energy. Zeroth Law of Thermodynamics: If two systems are separately in thermal equilibrium with a third system. The first two systems are in thermal equilibrium with each other. 1st Law of Thermodynamics (Law of Conservation of Energy): When heat flows into a system the energy must either appear as increased internal energy or work done by the system on its surroundings. Entropy: A quantitative measure of the disorder of a system. 2nd Law of Thermodynamics: The total entropy of the universe can never decrease. Natural processes tend towards disorder, greater entropy. Heat Engine: A device that converts thermal energy into mechanical work. Ideal Heat Engine: An engine with an efficiency of 1. Efficiency: The ratio of the work done by the heat engine to the heat input to the engine. 	<ul style="list-style-type: none"> T = Temperature, °C, K α = Linear expansion coefficient, (°C)⁻¹ β = Volume expansion coefficient, (°C)⁻¹ L = Length, m V = Volume, m³ U = Internal energy, J Q = Heat, J W = Work, J C_v = Specific heat, J/kg·°C m = Mass, kg C = Heat capacity, J/°C L_{fus} = Heat of Fusion, kJ/kg L_{vap} = Heat of Vaporization, kJ/kg S = Entropy, J/kg η = Efficiency
	<h3>Key Formulas</h3> <ul style="list-style-type: none"> $\Delta L = L \times \alpha \times \Delta T$ $\Delta V = V \times \beta \times \Delta T$ $\alpha \approx 3\beta$ $Q = C_v m \times \Delta T$ or $Q = C \times \Delta T$ where $C = C_v m$ $\Delta Q_{\text{sys}} = m \times L_{\text{fus}}$ $\Delta Q_{\text{sys}} = m \times L_{\text{vap}}$ $U = Q - W$ $\Delta S_{\text{sys}} > 0$ $\Delta S_{\text{sys}} + \Delta S_{\text{sur}} > 0$ $W = \frac{Q_{\text{out}}}{Q_{\text{in}}}$

1st Law of Thermodynamics1st Law of Thermodynamics

When heat flows into a system the energy must either appear as increased internal energy or work done by the system on its surroundings. This is a statement of the conservation of energy.

$$U = Q - W$$

Q is the heat added to the system.

W is positive when work is done by the system on its surroundings: $U = Q - W$

W is negative when work is done on the system, by surroundings: $U = Q - (-W) = Q + W$

Special cases of the 1st Law

Adiabatic: No heat transfer, $Q = 0$, $\Delta U = -W = -P\Delta V$

Constant-volume: No work is done, $W = 0$, $\Delta U = Q$

Cyclic: No change in internal energy, $\Delta U = 0$, $Q = -W$

Free expansion processes: Irreversible, $\Delta U = Q = W$

2nd Law of Thermodynamics

Entropy is a measure of disorder. If the entropy of the system decreases during a reaction, the entropy of the surroundings increases by an equal or greater amount.

Statements of the 2nd Law of Thermodynamics:

1) The total entropy of the universe can never decrease, only increase or remain the same. $\Delta S \geq 0$.

2) Heat flows from a hot object to a cold object but never the reverse.

3) There cannot be a 100% efficient heat engine; one that changes a given amount of heat entirely into work:

$$\eta = \frac{W_{\text{out}}}{Q_{\text{in}}} < 1$$

How to Use This Cheat Sheet: These are the keys related this topic. Try to read through it carefully twice then write it out on a blank sheet of paper. Review it again before the exam.

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Marco Cascella

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pedagogy that is based on research on how people learn and has been shown to lead to better student outcomes in many contexts and in a variety of academic disciplines. Beyond facilitating students' mastery of a discipline, it promotes vital educational outcomes such as communication skills and critical thinking. Its active international community of practitioners provides accessible educational development and support for anyone developing related courses. Having started as a process developed by a group of chemistry professors focused on helping their students better grasp the concepts of general chemistry, The POGIL Project has grown into a dynamic organization of committed instructors who help each other transform classrooms and improve student success. They develop curricular materials to assist this process, conduct research, expanding what is known about learning and teaching, and provide professional development and collegiality from elementary teachers to college professors. As a pedagogy, it has been shown to be effective in a variety of content areas and at different educational levels. This is an introduction to the process and the community. Every POGIL classroom is different and is a reflection of the uniqueness of the particular context: the institution, department, physical space, student body, and instructor, but follows a common structure in which students work cooperatively in self-managed small groups of three or four. The group work is focused on activities that are carefully designed and scaffolded to enable students to develop important concepts or to deepen and refine their understanding of those ideas or concepts for themselves, based entirely on data provided in class, not on prior reading of the textbook or other introduction to the topic. The learning environment is structured to support the development of process skills such as teamwork, effective communication, information processing, problem solving, and critical thinking. The instructor's role is to facilitate the development of student concepts and process skills, not to simply deliver content to the students. The first part of this book introduces the theoretical and philosophical foundations of POGIL pedagogy and summarizes the literature demonstrating its efficacy. The second part of the book focuses on implementing POGIL, covering the formation and effective management of student teams, offering guidance on the selection and writing of POGIL activities, as well as on facilitation, teaching large classes, and assessment. The book concludes with examples of implementation in STEM and non-STEM disciplines, as well as guidance on how to get started. Appendices provide additional resources and information about The POGIL Project.

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Table of Contents Acs Thermodynamics Practice Exam

1. Understanding the eBook Acs Thermodynamics Practice Exam
 - The Rise of Digital Reading Acs Thermodynamics Practice Exam
 - Advantages of eBooks Over Traditional Books
2. Identifying Acs Thermodynamics Practice Exam
 - Exploring Different Genres
 - Considering Fiction vs. Non-Fiction
 - Determining Your Reading Goals
3. Choosing the Right eBook Platform
 - Popular eBook Platforms
 - Features to Look for in an Acs Thermodynamics Practice Exam
 - User-Friendly Interface
4. Exploring eBook Recommendations from Acs Thermodynamics Practice Exam
 - Personalized Recommendations

- Acs Thermodynamics Practice Exam User Reviews and Ratings
- Acs Thermodynamics Practice Exam and Bestseller Lists

5. Accessing Acs Thermodynamics Practice Exam Free and Paid eBooks

- Acs Thermodynamics Practice Exam Public Domain eBooks
- Acs Thermodynamics Practice Exam eBook Subscription Services
- Acs Thermodynamics Practice Exam Budget-Friendly Options

6. Navigating Acs Thermodynamics Practice Exam eBook Formats

- ePUB, PDF, MOBI, and More
- Acs Thermodynamics Practice Exam Compatibility with Devices
- Acs Thermodynamics Practice Exam Enhanced eBook Features

7. Enhancing Your Reading Experience

- Adjustable Fonts and Text Sizes of Acs Thermodynamics Practice Exam
- Highlighting and Note-Taking Acs Thermodynamics Practice Exam
- Interactive Elements Acs Thermodynamics Practice Exam

8. Staying Engaged with Acs Thermodynamics Practice Exam

- Joining Online Reading Communities
- Participating in Virtual Book Clubs
- Following Authors and Publishers Acs Thermodynamics Practice Exam

9. Balancing eBooks and Physical Books Acs Thermodynamics Practice Exam

- Benefits of a Digital Library
- Creating a Diverse Reading Collection Acs Thermodynamics Practice Exam

10. Overcoming Reading Challenges

- Dealing with Digital Eye Strain
- Minimizing Distractions
- Managing Screen Time

11. Cultivating a Reading Routine Acs Thermodynamics Practice Exam

- Setting Reading Goals Acs Thermodynamics Practice Exam
- Carving Out Dedicated Reading Time

12. Sourcing Reliable Information of Acs Thermodynamics Practice Exam

- Fact-Checking eBook Content of Acs Thermodynamics Practice Exam

- Distinguishing Credible Sources
- 13. Promoting Lifelong Learning
 - Utilizing eBooks for Skill Development
 - Exploring Educational eBooks
- 14. Embracing eBook Trends
 - Integration of Multimedia Elements
 - Interactive and Gamified eBooks

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