THE CURIOUS SCIENTIST AI

THERMODYNAMICS

A FOCUSED GUIDE FOR HSC STAGE 6 PHYSICS

EMERGENT MIND PRESS

Introduction

Welcome to HSC Physics! You are about to embark upon an extraordinary journey, exploring the fundamental laws that govern our universe—from the smallest subatomic particles to the vast expanses of galaxies. Physics is a remarkable field of study that challenges our perceptions and sharpens our curiosity, imagination, and analytical skills. It enables us to comprehend the natural phenomena around us and equips us with the tools to solve complex problems in our ever-changing world.

This textbook is specifically tailored for advanced students following the NSW HSC curriculum. Our goal is to support your unique strengths, interests, and learning styles, and to provide a challenging yet accessible resource that prepares you thoroughly for your Higher School Certificate (HSC) Physics examinations.

How to Use This Textbook

The textbook is carefully structured to help you navigate through the course content effectively. It includes several features specifically designed to accommodate diverse learning styles and to encourage active engagement with Physics concepts.

Main Text

The main text systematically presents each topic within the HSC syllabus, clearly explaining the core concepts, theories, and laws of Physics. Throughout the chapters, explanations are supported by examples, diagrams, and step-by-step problem-solving demonstrations.

Margin Notes

Margin notes are provided alongside the main text, offering additional insights, clarifications, and historical context. These notes are intended to enrich your understanding and to spark curiosity. Margin notes may include:

- **Historical Insights:** Brief accounts of discoveries, biographies of influential physicists, and historical developments.
- **Concept Checks:** Short questions or reflections to test your understanding as you progress through a section.
- **Quick Tips:** Study strategies, memory aids, and helpful reminders to reinforce essential concepts.

Investigations and Activities

Physics is fundamentally an experimental science. Throughout this book, you will encounter investigations and hands-on activities designed to deepen your conceptual understanding and develop your skills in scientific inquiry. Each investigation clearly outlines objectives, required materials, safety considerations, and guided instructions.

Physics is best understood through direct experience and inquiry.

Worked Examples and Practice Problems

Worked examples illustrate step-by-step solutions to typical problems encountered in HSC examinations. Practice problems follow each section, allowing you to apply your knowledge and to build confidence in problem-solving techniques.

Chapter Summaries and Review Questions

At the conclusion of each chapter, summaries consolidate the key ideas and concepts discussed, while review questions and exam-style problems provide opportunities to revise and reflect upon your learning.

Overview of the NSW HSC Physics Course

The NSW HSC Physics syllabus comprises two distinct stages: the Year 11 (Preliminary) course and the Year 12 (HSC) course. Each stage encompasses specific modules, as outlined below.

Year 11 (Preliminary) Modules

In Year 11, you will build foundational knowledge and skills to prepare for the more advanced concepts studied in Year 12. The Preliminary course consists of four modules:

1. **Kinematics:** Discover how objects move, exploring displacement, velocity, acceleration, and motion graphs.
2. **Dynamics:** Investigate forces, Newton's laws of motion, and applications such as friction and projectile motion.

3. **Waves and Thermodynamics:** Explore wave phenomena, properties of sound and light, and the fundamental concepts of heat and temperature.

4. **Electricity and Magnetism:** Examine electrical circuits, magnetism, electromagnetic forces, and their real-world applications.

Year 12 (HSC) Modules

In Year 12, you will deepen your understanding, applying concepts from the Preliminary course to more complex scenarios, phenomena, and technologies. The HSC course consists of four modules:

1. **Advanced Mechanics:** Extend your knowledge of motion and forces, examining circular motion, projectile motion, and gravitational fields.

2. **Electromagnetism:** Delve deeper into magnetic fields, electromagnetic induction, electric motors, generators, and transformers.

3. **The Nature of Light:** Investigate the wave-particle duality of light, including interference, diffraction, and quantum concepts such as photons and photoelectric effects.

4. **From the Universe to the Atom:** Explore cosmology, astrophysics, nuclear physics, and the fundamental nature of matter, energy, and radiation.

How to Use This Textbook Effectively

Effective learning in Physics involves consistent engagement, focused practice, and strategic preparation. Consider the following recommendations to maximise your success in HSC Physics.

Study Tips

- **Active Engagement:** Regularly participate in class discussions, investigations, and collaborative activities. Physics requires active thinking and questioning.

- **Consistent Revision:** Regularly review concepts, formulas, and definitions. Frequent revision consolidates memory and enhances long-term retention.

- **Problem-Solving Practice:** Consistently attempt practice problems and past HSC exam questions to build strong problem-solving skills.

- **Use Margin Notes Wisely:** Margin notes offer concise and accessible insights. Use these notes as quick references for revision and to further explore areas of interest.

- **Adapt to Your Learning Style:** Recognise what works best for you—visual diagrams, hands-on experiments, verbal explanations, or written summaries—and adapt your study methods accordingly.

Navigation and Organisation

- **Table of Contents and Index:** Familiarise yourself with the structure of the textbook. Use the table of contents to plan your study schedule and the index to locate specific topics quickly.

- **Margin Space:** Utilise the generous margin space provided in this textbook to write notes, highlight important information, or pose questions for further exploration.

Preparation for HSC Examinations

- **Understanding the Syllabus:** Clearly understand the HSC Physics syllabus outcomes, content, and assessment criteria. Align your study and revision strategies accordingly.

- **Practice Examination Conditions:** Regularly practise completing exam-style questions under timed conditions to become familiar with examination scenarios.

- **Seek Feedback:** Regularly discuss your understanding and performance with teachers or peers. Constructive feedback is invaluable for identifying areas for improvement.

The Nature and Importance of Physics

Physics is not only a discipline of knowledge but a way of thinking. Physicists are inquisitive, critical, and creative individuals who use logic, experimentation, and mathematics to solve problems and understand the universe.

"Physics is about questioning, studying, probing nature. You probe, and if you're lucky, you get strange clues."—Lene Hau, Physicist

Physics reveals the underlying rules that govern our universe. It has led to transformative technological advancements—from electricity generation and medical imaging to spacecraft navigation and quantum computing. As you study Physics, you will develop skills in critical thinking, problem solving, mathematical reasoning, and experimental design, all of which are invaluable in diverse careers and fields of study.

Moreover, Physics fosters a deep appreciation of nature's elegance and complexity. It encourages curiosity, inspires innovation, and prompts us to ask profound questions about our place in the universe.

A Word of Encouragement

As you begin this exciting journey, remember that learning Physics is both challenging and rewarding. You may encounter concepts that initially seem complex or abstract—this is entirely normal. Persevere, embrace curiosity, and remain open to exploring ideas in diverse ways. Seek support and collaboration, and actively engage with the resources provided in this textbook.

By approaching your study of Physics with enthusiasm, curiosity, and determination, you will gain an invaluable understanding of the natural world and acquire skills that will serve you well throughout your life.

Welcome to HSC Physics. We look forward to exploring the wonders of physics with you!

Thermodynamics

This chapter delves into the principles of thermodynamics, exploring the fundamental relationship between heat, energy, and the behaviour of matter at the microscopic level. We will investigate how temperature relates to particle motion, how thermal energy is transferred, and the concepts governing energy transformations and equilibrium. Building on our understanding of energy transfer from waves, we now focus on the thermal domain.

Inquiry Questions:

- *How are temperature, thermal energy, and particle motion related?*
- *How does energy transformation underpin the laws of thermodynamics? (Focus here on energy transfer mechanisms and quantification)*
- *What predicts and determines the direction and efficiency of energy transfer? (Focus here on equilibrium and heat capacity)*

Syllabus Outcomes Covered: *PH11-10, PH11/12-3, PH11/12-4, PH11/12-6, PH11/12-7*

Syllabus Ref: PH11-10 (ACSPH018)
Bloom's Level: Understand
Literacy Skills: Define temperature, Explain particle energy distribution, Relate kinetic energy to temperature.
Numeracy Skills: Interpret particle energy distributions graphically.

Video Resource: See this video for a visual explanation.

Temperature, Thermal Energy, and Particle Motion

Our understanding of heat and temperature is grounded in the **particle model of matter**, which describes substances as being composed of constantly moving particles (atoms or molecules). The energy associated with this motion is crucial to thermodynamics.

Key Concept: Temperature and Kinetic Energy

Temperature is a measure of the average kinetic energy of the particles within a substance. It reflects how vigorously, on average, the particles are moving (translating, vibrating, rotating). **Thermal energy**, on the other hand, represents the total internal energy of a substance due to the kinetic *and* potential energy of its particles. It depends not only on temperature but also on the mass and type of substance.

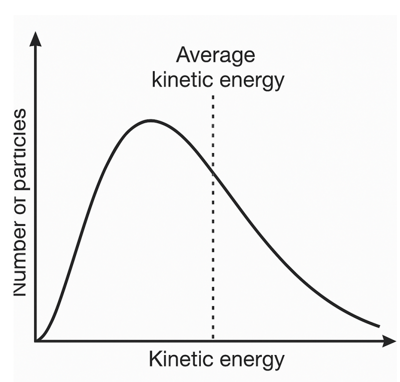


Figure 1: A typical distribution of kinetic energies among particles in a substance at a given temperature. Higher temperatures shift the average energy to the right and broaden the distribution.

It's important to distinguish between temperature and thermal energy. A large body of water (like a swimming pool) at a lower temperature can contain significantly more thermal energy than a small cup of water at a higher temperature because it has vastly more particles, even if their average kinetic energy is lower.

Stop and Think

Consider a litre of water at 80°C and 10 litres of water at 20°C. Which has the higher temperature? Which contains more thermal energy? Explain your reasoning based on the particle model.

* **Challenge:** Research the difference between translational, rotational, and vibrational kinetic energy for molecules. How do these contribute differently to the thermal energy of solids, liquids, and gases?

History: The connection between heat and particle motion was solidified by scientists like James Prescott Joule in the mid-19th century, challenging the earlier 'caloric' theory of heat as a fluid.

Related HSC Question: HSC2020Q14b

Thermal Equilibrium

When objects at different temperatures are brought into thermal contact, energy naturally flows from the hotter object to the colder one. This process continues until the objects reach a state of **thermal equilibrium**.

Key Concept: Thermal Equilibrium

Thermal equilibrium is the state reached when two or more objects in thermal contact cease to have any net transfer of thermal energy between them. At equilibrium, they are at the same temperature. This concept is fundamental to the **Zeroth Law of Thermodynamics**, which states that if two systems are each in thermal equilibrium with a third system, then they are in thermal equilibrium with each other.

Syllabus Ref: PH11-10 (ACSPH022)

Bloom's Level: Analyse

Literacy Skills: Define thermal equilibrium, Explain energy transfer directions, Summarise Zeroth Law.

Numeracy Skills: Interpret equilibrium diagrams.

Demo Video: See [this video] for a demonstration.

Related HSC Question: HSC2019Q12a

Think about placing a thermometer in warm water. The thermometer's reading increases as thermal energy flows from the water to the thermometer. The reading stabilises when the thermometer reaches thermal equilibrium with the water – they are at the same temperature, and there is no further net energy transfer. Similarly, a hot drink left on a table will cool down until it reaches thermal equilibrium with the surrounding air.

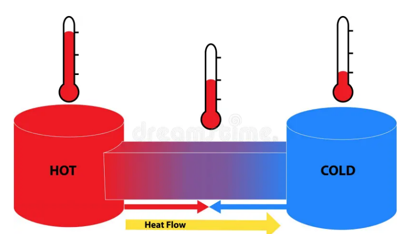


Figure 2: Two objects, A (hot) and B (cold), in thermal contact. Heat flows from A to B until $T_A = T_B$, reaching thermal equilibrium. No net heat flow occurs at equilibrium.

Stop and Think

Why is the term 'net' transfer important when discussing thermal equilibrium? Do particles stop exchanging energy altogether?

Quantifying Heat Transfer: Specific Heat Capacity

Different substances require different amounts of thermal energy to change their temperature by the same amount. This property is quantified by the **specific heat capacity**.

Key Concept: Specific Heat Capacity (c)

Specific heat capacity (c) is the amount of thermal energy required to raise the temperature of one kilogram of a substance by one Kelvin (or one degree Celsius). Its unit is Joules per kilogram per Kelvin (J kg^{-1} K^{-1}) or Joules per kilogram per degree Celsius (J kg^{-1} °C^{-1}). The relationship between thermal energy transferred (Q), mass (m), specific heat capacity (c), and temperature change (ΔT) is given by:

$$Q = mc\Delta T \tag{1}$$

where $\Delta T = T_{final} - T_{initial}$. A positive Q indicates energy absorbed by the substance, while a negative Q indicates energy released.

Water has a very high specific heat capacity compared to many other substances. This means it takes a lot of energy to heat water up, and water releases a lot of energy when it cools down. This property is crucial for climate regulation (large bodies of water moderate temperature changes) and in biological systems.

Example:

How much thermal energy is required to heat 2.0 kg of water from 20°C to 80°C? (Use $c_{water} = 4186$ J kg^{-1} K^{-1})

Solution: Identify the known values: $m = 2.0$ kg $c = 4186$ J kg^{-1} K^{-1} $T_{initial} = 20$°C $T_{final} = 80$°C Calculate the temperature change: $\Delta T = T_{final} - T_{initial} = 80C - 20C = 60$°C (or 60 K) Apply the formula: $Q = mc\Delta T$ $Q = (2.0\,\text{kg}) \times (4186\,\text{J kg}^{-1}\,\text{K}^{-1}) \times (60\,\text{K})$ $Q = 502320$ J $Q \approx 5.0 \times 10^5$ J (or 500 kJ)

Therefore, approximately 500 kJ of thermal energy is required.

Investigation: Determining Specific Heat Capacity Experimentally

Aim: To experimentally determine the specific heat capacity of a metal block (e.g., aluminium).

Apparatus: Metal block of known mass, immersion heater,

Syllabus Ref: PH11-10 (ACSPH020)

Working Scientifically: Problem Solving

Bloom's Level: Apply

Literacy Skills: Define specific heat capacity, Interpret heat capacity tables.

Numeracy Skills: Calculate thermal energy and temperature change using Q=mcΔT, Analyse experimental data.

Video Resource: See this video for a visual explanation.

Related HSC Question: HSC2021Q15

Math Link: Ensure you can rearrange Equation 1 to solve for m, c, or ΔT. Pay close attention to units. A temperature *change* (ΔT) is the same in Kelvin and Celsius, but the absolute temperatures are different.

Substance	c (J kg^{-1} K^{-1})
Water (liquid)	4186
Ice (0°C)	2090
Aluminium	900
Copper	385
Air (typical)	1005

Figure 3: Approximate specific heat capacities of common substances. Note water's high value.

power supply, voltmeter, ammeter, thermometer, stopwatch, insulation.
Method Outline:

1. Measure the mass (m) of the metal block.
2. Record the initial temperature ($T_{initial}$) of the block.
3. Insert the heater and thermometer into holes in the block. Ensure good thermal contact (a drop of oil can help). Insulate the block.
4. Connect the heater to the power supply via the ammeter (series) and voltmeter (parallel).
5. Start the stopwatch and switch on the power supply simultaneously. Record voltage (V) and current (I).
6. Record the temperature (T) at regular intervals (e.g., every minute) for a set time (e.g., 10 minutes).
7. Switch off the power supply. Record the maximum temperature reached (T_{final}).

Analysis:

- Calculate the electrical energy supplied: $E = V \times I \times t$, where t is the total time in seconds.
- Assuming all electrical energy is converted to thermal energy absorbed by the block ($Q \approx E$), calculate $\Delta T = T_{final} - T_{initial}$.
- Rearrange $Q = mc\Delta T$ to find c: $c = \frac{Q}{m\Delta T} \approx \frac{VIt}{m\Delta T}$.
- Compare the experimental value with the known value and discuss sources of error (e.g., heat loss to surroundings, thermometer calibration, energy absorbed by heater/insulation).

Safety Checklist: [ ] Ensure electrical connections are secure. [ ] Do not touch the heater when hot. [ ] Place apparatus away from edge of bench.
Working Scientifically Focus: Conducting Investigations (PH11/12-3), Processing Data (PH11/12-4), Problem Solving (PH11/12-6).

* **Challenge:** How would you modify the specific heat capacity experiment to account for heat loss to the surroundings more accurately? Research techniques like the method of mixtures or continuous flow calorimetry.

Mechanisms of Heat Transfer

Thermal energy transfer occurs through three primary mechanisms: conduction, convection, and radiation. Often, more than one mechanism is active simultaneously.

Syllabus Ref: PH11-10 (ACSPH016)
Bloom's Level: Understand
Literacy Skills: Describe energy transfer mechanisms, Compare mechanisms.
Numeracy Skills: Interpret insulation performance graphs.
Diagram Resource: See 'heat-flow-hot-cold-objects.png'.
Related HSC Question: HSC2018Q9a

Conduction

Conduction is the transfer of thermal energy through direct contact and collisions between adjacent particles (atoms, molecules, electrons) without the bulk movement of the substance itself. It is the primary mechanism of heat transfer in solids.

- **Mechanism:** Vibrating particles collide with neighbours, transferring kinetic energy. In metals, free electrons also play a significant role, making metals good thermal conductors.
- **Examples:** A metal spoon heating up in hot soup, heat travelling along an iron bar held in a flame.
- **Factors:** Depends on the material (thermal conductivity), temperature difference, cross-sectional area, and length.

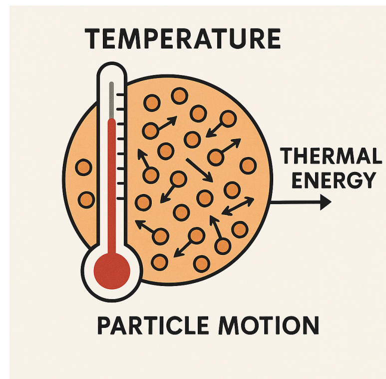


Figure 4: Conduction: Heat energy transferred through particle collisions along a solid rod.

Convection

Convection is the transfer of thermal energy through the bulk movement of fluids (liquids or gases). It occurs due to changes in density caused by temperature differences.

- **Mechanism:** When a fluid is heated from below, it expands, becomes less dense, and rises. Cooler, denser fluid sinks to take its place, creating a **convection current**.
- **Examples:** Boiling water in a pot, sea breezes, atmospheric circulation, central heating systems.
- **Types:** Natural convection (driven by density differences) and forced convection (driven by external means like fans or pumps).

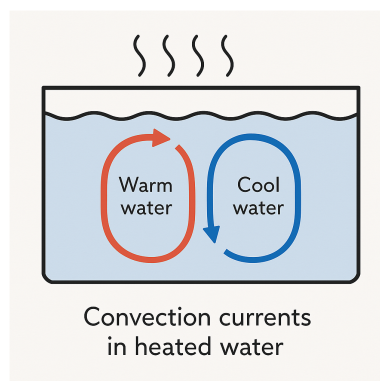


Figure 5: Convection currents in heated water. Warm, less dense water rises; cool, denser water sinks.

Radiation

Radiation is the transfer of thermal energy via electromagnetic waves (primarily infrared radiation). Unlike conduction and convection, radiation does not require a medium and can travel through a vacuum.

- **Mechanism:** All objects above absolute zero emit thermal radiation. The rate of emission depends on temperature, surface area, and emissivity (a measure of how effectively a surface radiates). Hotter objects radiate more energy.

- **Examples:** Heat from the Sun reaching Earth, warmth felt near a campfire or radiator, thermal imaging cameras.
- **Surface Properties:** Dull, black surfaces are good absorbers and emitters of radiation, while shiny, light-coloured surfaces are poor absorbers/emitters but good reflectors.

Stop and Think

Explain how a thermos flask (vacuum flask) minimizes heat transfer by all three mechanisms (conduction, convection, radiation) to keep liquids hot or cold.

Phase Changes and Latent Heat

When a substance absorbs or releases thermal energy, its temperature may change (as described by specific heat capacity), or it may undergo a **phase change** (e.g., melting, boiling, freezing, condensing) at a constant temperature. The energy involved in phase changes is called **latent heat**.

Key Concept: Latent Heat (L)

Latent heat (L) is the thermal energy absorbed or released per unit mass of a substance during a phase change at constant temperature and pressure.

- **Latent Heat of Fusion** (L_f): Energy required to change 1 kg of substance from solid to liquid (melting) or released when changing from liquid to solid (freezing).
- **Latent Heat of Vaporization** (L_v): Energy required to change 1 kg of substance from liquid to gas (boiling/evaporation) or released when changing from gas to liquid (condensation).

The thermal energy (Q) required for a mass (m) to undergo a phase change is given by:

$$Q = mL \tag{2}$$

The unit for latent heat is Joules per kilogram (J kg^{-1}).

During a phase change, the absorbed energy (latent heat) increases the potential energy of the particles (breaking intermolecular bonds) rather than their average kinetic energy (temperature). This is why the temperature remains constant during melting or boiling.

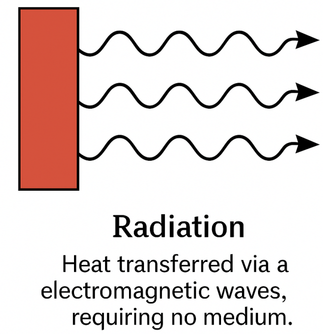


Figure 6: Radiation: Heat transferred via electromagnetic waves, requiring no medium.

* **Challenge:** Research the concept of thermal conductivity (for conduction), convective heat transfer coefficient (for convection), and emissivity (for radiation). How are these quantified and used in engineering applications like building insulation or heat exchanger design?

History: Early theories struggled to explain heat transfer through vacuum until James Clerk Maxwell's theory of electromagnetism (1860s) provided the basis for understanding thermal radiation.

Math Link: Be careful! Use $Q = mc\Delta T$ when temperature changes, and $Q = mL$ when phase changes occur at constant temperature. Problems often involve multiple steps combining both equations.

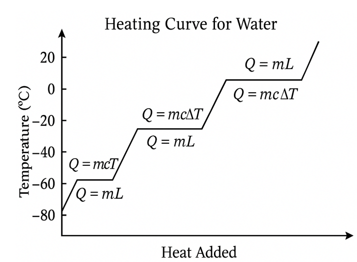


Figure 7: Heating curve for water. Sloped sections represent temperature increases (Q=mcΔT applies). Flat sections represent phase changes at constant temperature (Q=mL applies): melting at 0°C and boiling at 100°C.

Syllabus Ref: PH11-10

Working Scientifically: Processing Data and Information
Bloom's Level: Analyse

Literacy Skills: Interpret phase change graphs.

Numeracy Skills: Calculate latent heat using Q=mL, Analyse heating/cooling curves rigorously.

Video Resource: See this video for a visual explanation.

Related HSC Question: HSC2019Q13b

Example:

Calculate the total thermal energy required to convert 500 g of ice at 0°C to steam at 100°C. (Use L_f(water) $= 3.34 \times 10^5$ J kg^{-1}, c(water) $= 4186$ J kg^{-1} K^{-1}, L_v(water) $= 2.26 \times 10^6$ J kg^{-1})
Solution: This requires three steps: 1. Melting the ice at 0°C: $Q_1 = mL_f$ 2. Heating the water from 0°C to 100°C: $Q_2 = mc\Delta T$ 3. Boiling the water at 100°C: $Q_3 = mL_v$
Convert mass to kg: $m = 500\,\mathrm{g} = 0.500\,\mathrm{kg}$ Calculate ΔT for water heating: $\Delta T = 100C - 0C = 100$ K
1. $Q_1 = (0.500\,\mathrm{kg}) \times (3.34 \times 10^5\,\mathrm{J\,kg^{-1}}) = 1.67 \times 10^5$ J 2. $Q_2 = (0.500\,\mathrm{kg}) \times (4186\,\mathrm{J\,kg^{-1}\,K^{-1}}) \times (100\,\mathrm{K}) = 2.093 \times 10^5$ J 3. $Q_3 = (0.500\,\mathrm{kg}) \times (2.26 \times 10^6\,\mathrm{J\,kg^{-1}}) = 1.13 \times 10^6$ J
Total energy: $Q_{total} = Q_1 + Q_2 + Q_3$ $Q_{total} = (1.67 + 2.093 + 11.3) \times 10^5$ J $Q_{total} = 15.063 \times 10^5\ \mathrm{J} \approx 1.51 \times 10^6$ J (or 1.51 MJ)
Therefore, approximately 1.51 MJ of energy is required.

Stop and Think

Why does steam at 100°C cause more severe burns than water at 100°C? Relate your answer to latent heat.

* **Challenge:** Investigate the phenomenon of evaporative cooling. Explain how the evaporation of sweat helps regulate body temperature, linking it to the latent heat of vaporization.

Depth Study Idea: Experimentally determine the latent heat of fusion of ice using calorimetry. Identify key sources of uncertainty.

Chapter Summary & Further Connections

This chapter explored fundamental thermodynamic concepts:

- **Temperature** relates to the average kinetic energy of particles.
- **Thermal Energy** is the total internal energy.
- **Thermal Equilibrium** is reached when there is no net heat flow (equal temperatures).
- **Specific Heat Capacity** ($Q = mc\Delta T$) quantifies energy needed for temperature change.
- **Heat Transfer Mechanisms** are conduction, convection, and radiation.
- **Latent Heat** ($Q = mL$) quantifies energy needed for phase changes at constant temperature.

These principles have broad applications, from understanding weather patterns and climate change (linking to Environmental Science and the cross-curriculum priority of Sustainability) to designing efficient engines and refrigeration systems. The energy changes involved in phase transitions and chemical reactions (studied in Chemistry) are also governed by thermodynamic principles. Developing solutions to global energy challenges relies heavily on applying and advancing our understanding of thermodynamics.

Practice Questions

Practice Questions - Basic

1. Define temperature in terms of particle motion.
2. State the formula for calculating thermal energy change related to specific heat capacity, defining each term.
3. List the three main mechanisms of heat transfer.
4. What is latent heat? Give one example of where it is relevant.
5. Calculate the energy required to heat 0.5 kg of aluminium from 20°C to 100°C. (Use $c_{Al} = 900$ J kg^{-1} K^{-1})

Practice Questions - Intermediate

1. Explain the difference between thermal energy and temperature using a macroscopic example (e.g., ocean vs boiling kettle).
2. Describe the process of reaching thermal equilibrium between a hot metal block and cool water in a calorimeter.
3. A 2.0 kW heater is used to heat 5.0 kg of water initially at 15°C for 3 minutes. Assuming no heat loss, calculate the final temperature of the water. (Use $c_{water} = 4186$ J kg^{-1} K^{-1})
4. Compare and contrast conduction and convection, giving examples where each is the dominant mode of heat transfer.
5. Calculate the energy released when 200 g of steam at 100°C condenses to water at 100°C. (Use $L_v(\text{water}) = 2.26 \times 10^6$ J kg^{-1})
6. Sketch a cooling curve (Temperature vs Time) for a substance that starts as a gas, cools, condenses to a liquid, cools further, freezes to a solid, and finally cools as a solid. Label the sections corresponding to specific heat and latent heat.

Practice Questions - Advanced

1. A 100 g copper block at 90°C is placed into 300 g of water at 20°C in an insulated container. Calculate the final equilibrium temperature, assuming no heat loss to the container. (Use $c_{Cu} = 385$ J kg^{-1} K^{-1}, $c_{water} = 4186$ J kg^{-1} K^{-1}) *Hint: Heat lost by copper = Heat gained by water.*

2. Design an experiment to compare the effectiveness of different insulating materials (e.g., wool, foam, air gap) in reducing heat transfer by conduction and convection. Specify your independent, dependent, and controlled variables, and outline your method and data analysis approach. (Focus on experimental design and scientific process - PH11/12-3, PH11/12-6).

3. (PISA-style) A company is designing a new type of solar water heater for residential use. They are considering two designs: one using copper pipes painted black, and another using plastic pipes with a selective coating that absorbs sunlight well but emits little infrared radiation. Analyse the potential advantages and disadvantages of each design in terms of heat absorption (radiation), heat transfer to the water (conduction/convection), and heat loss to the environment (all three mechanisms). Justify which design might be more efficient overall, considering different climate conditions. (Focus on applying concepts to a real-world problem, evaluating designs - PH11-10, PH11/12-6, PH11/12-7).

4. Explain quantitatively why sweating is an effective cooling mechanism for the human body, even on a hot day when the surrounding air temperature might be higher than body temperature. Use the concept of latent heat of vaporization in your explanation.

5. How much energy is required to convert 1.0 kg of ice initially at -10°C completely into steam at 110°C? You will need specific heat capacities for ice and steam, in addition to water, plus both latent heats. (Requires finding additional data - PH11/12-4). (Example values: $c_{ice} \approx 2090$, $c_{steam} \approx 2010$ J kg^{-1} K^{-1}).

Lesson Pack One

Year 11 Physics - Lesson Plan 1/3
Thermodynamics: Particles, Temperature Energy Flow

Philip Haynes

Based on NSW Stage 6 Syllabus (Module 3)

Lesson Overview

- **Lesson Title:** Thermodynamics: Relating Particles, Temperature, and Energy Transfer
- **Duration:** 60 minutes
- **Focus Inquiry Question:** How are temperature, thermal energy, and particle motion related? (Introduction to Q3: direction of energy transfer)

Syllabus Alignment Knowledge Nodes Targeted

- **Outcomes:** PH11-10, PH11/12-3 (Conduct Invest.), PH11/12-7 (Communicate)
- **Content:** ACSPH018, ACSPH016, ACSPH022 (conceptual intro)
- **Knowledge Nodes:** N1 (Temp/KE Relation), N4 (Transfer Mechanisms), N2 (Thermal Equilibrium - Concept)

Student Learning Objectives (Aligned with Nodes)

Students will be able to:

- Explain the relationship between temperature and the average kinetic energy of particles (N1 - Understand).
- Identify and describe conduction, convection, and radiation with examples (N4 - Understand).
- Explain conduction in solids using the particle model (N4 - Understand).
- Define thermal equilibrium conceptually as no net energy transfer (N2 - Understand).
- Predict the direction of heat flow based on temperature differences (Links N1, N2, Inquiry Q3).

Literacy Define temperature, thermal energy, conduction, convection, radiation, thermal equilibrium precisely (N1, N4, N2).

Numeracy Qualitatively interpret particle energy distributions/visualisations (N1).

Lesson Structure & Activities

Introduction (10 mins)

- **Teacher Activity:** Display Inquiry Questions 1, 2, 3. State focus on Q1. Engage with prompt: "Metal vs wood chair feeling cold/warm". Facilitate brief discussion. Introduce Thermodynamics scope. Provide historical (Steam Engine) and future (Climate/IT) context. Define core terms on board/slide: Temperature (Avg KE), Thermal Energy (Total KE+PE), Heat (Transfer of TE). [N1 Definitions]

- **Student Activity:** Note Inquiry Questions. Participate in discussion. Record key definitions from board/slide (support via Worksheet 1).
- **Pedagogy Focus:** Contextualization (Motivation), Activate Prior Knowledge, Core Terminology (Literacy N1).

Exploration (30 mins)

- **Teacher Activity:** Conduct/Show Demo/Simulations (See Activity Sheet 1 for details):
  - Conduction (N4): Heat metal rod, explain particle vibration transfer.
  - Convection (N4): Show video/sim of convection currents, explain density changes.
  - Radiation (N4): Use IR camera/heat lamp/sim, explain EM wave transfer. Link to user prompt: hot metal radiating heat and light.

  Guide PhET Simulation "Energy Forms and Changes" exploration (link on Activity Sheet 1). Focus on particle view vs. temperature (N1). Introduce Equilibrium concept (N2) - what happens when hot/cold objects touch? Discuss direction of flow (Inquiry Q3 link).
- **Student Activity:** Observe demos/sims, explain using particle model (N1, N4). Use PhET simulation on laptops, guided by Worksheet 1 prompts. Discuss equilibrium concept. Complete relevant parts of Worksheet 1.
- **Pedagogy Focus:** Active Learning (Observation/Prediction), Multimodal Input (Demo/Sim), Visualising Microscopic Processes (N1, N4), Guided Inquiry (N2). Cognitive Science: Dual Coding, reducing load via visualisation.
- **ICT Integration:** PhET Simulation.

Consolidation (20 mins)

- **Teacher Activity:** Lead class discussion summarising N1, N4. Explicitly address metal/wood chair question using conduction/conductivity concept (N4). Reiterate equilibrium concept (N2) and direction of heat flow. Distribute Worksheet 1 for completion. Distribute #MarkSense Quiz 1.
- **Student Activity:** Participate in discussion, complete Worksheet 1 (definitions, explanations for N1, N4, N2 concept). Complete #MarkSense Quiz 1 (end of class or homework).
- **Pedagogy Focus:** Concept Consolidation, Linking Micro-Macro, Formative Assessment.

Resources Required

- Teacher demonstrations materials (metal rod, heat source, etc. - See Activity Sheet 1) OR Simulation/Video access.
- Student laptops with internet access.
- PhET Simulation links (on Activity Sheet 1).
- Worksheet 1 (separate PDF).
- #MarkSense Quiz 1 (included on Worksheet 1 PDF).
- Projector/Whiteboard.

Assessment

- **Formative:** Teacher observation of student participation in discussions and simulation use. Review of Worksheet 1 responses. Analysis of #MarkSense Quiz 1 results.

Differentiation

- **Support:** Provide sentence starters for explanations on worksheet. Pair students for simulation exploration. Pre-teach key vocabulary.
- **Extension:** Ask students to research specific thermal conductivity values and explain differences. Challenge students to explain convection in weather patterns.

Thermodynamics Lesson 1: Particles, Temperature & Energy Flow

Mr Haynes

Gosford High School

April 8, 2025

Outline

Introduction: Why Study Thermodynamics?

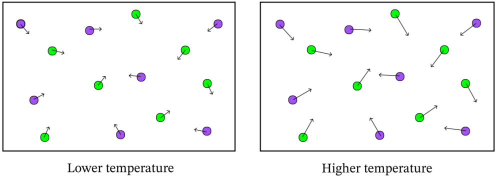
Focus Inquiry Question 1: How are temperature, thermal energy, and particle motion related?

- **Definition:** The study of energy, its transfer (heat, work), and transformations.
- **Think/Pair/Share:** Why does a metal chair feel colder than a wooden one at the same room temperature?
- **Relevance:**
  - *Historical:* Driven by the need to understand and improve Steam Engines (Industrial Revolution).
  - *Future:* Crucial for Climate Science (energy efficiency), Sustainable Technologies, Computing (heat limits).
- **Key Terms (Worksheet 1):**
  - Temperature (Measure of *average* particle Kinetic Energy - KE) [N1]
  - Thermal Energy (Total internal energy - KE + Potential Energy) [N1]
  - Heat (Transfer of thermal energy due to temperature difference)

Temperature and Particle Kinetic Energy

- Matter is made of particles (atoms/molecules) constantly in motion.
- Temperature is directly related to the *average* kinetic energy of these particles.
- Higher Temperature $\implies$ Higher Average KE $\implies$ Faster Particle Motion (vibration, translation, rotation).
- Lower Temperature $\implies$ Lower Average KE $\implies$ Slower Particle Motion.

Visualisation: PhET Simulation "Energy Forms and Changes" shows this link.



Observe particle speed increasing as heat is added.

Mechanisms of Heat Transfer

Heat (thermal energy) transfers via three main mechanisms:

1. **Conduction**
   - Transfer through direct particle collisions.
   - Dominant in solids.
   - Faster in materials with closely packed particles / free electrons (e.g., metals).
   - *Example:* Hot spoon handle.

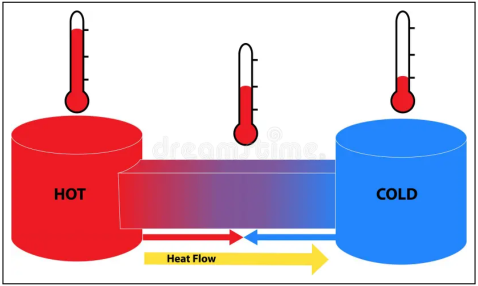
2. **Convection**
   - Transfer by the movement of fluids (liquids/gases).
   - Hotter fluid is less dense and rises; cooler fluid sinks. Creates currents.
   - *Example:* Boiling water, sea breeze.

3. **Radiation**
   - Transfer via electromagnetic waves (infrared).
   - Requires NO medium.
   - All objects above absolute zero radiate.
   - *Example:* Heat from sun, warmth from a fire.

Activity 1 provides demonstrations/simulations for these.

Thermal Equilibrium

- **Direction of Flow (Inquiry Q3 link):** Heat naturally flows from a hotter object to a colder object when they are in thermal contact.
- **Equilibrium Definition:** The state reached when there is **no net flow** of heat between objects in thermal contact.
- **Condition:** This occurs when the objects reach the **same temperature**.
- *Example:* A cold drink eventually warms up to room temperature. The drink and the room air reach thermal equilibrium.



Lesson 1 Summary

- Thermodynamics studies energy transfer and transformation.
- Temperature reflects average particle kinetic energy [N1].
- Heat is energy transferred due to temperature differences.
- Heat transfers via Conduction, Convection, Radiation [N4].
- Thermal Equilibrium is reached when temperatures are equal (no net heat flow) [N2].

Next Steps:

- Complete Worksheet 1 (Definitions, Explanations).
- Complete #MarkSense Quiz 1 (Check understanding).
- Preview Lesson 2: Quantifying heat transfer (Calculations!).

Thank you!

Questions?

Year 11 Physics - Activity Sheet 1
Demonstrating Heat Transfer Mechanisms

Thermodynamics

Module 3 - Lesson 1

Aim

To observe and explain the three primary mechanisms of heat transfer: conduction, convection, and radiation, and relate these to particle motion and temperature changes.

Knowledge Nodes Targeted

- N1: Temp/KE Relation (Observing effect of heating)
- N4: Transfer Mechanisms (Identifying and explaining each mode)
- N2: Thermal Equilibrium (Conceptual introduction via heat flow direction)

Part A: Demonstrations (Teacher Led or Video/Simulation)

Demo 1: Conduction

- **Materials:** Metal rod (e.g., copper or aluminium), heat source (Bunsen burner or torch), heat-resistant mat, (optional: thermal camera, wax dots along rod).
- **Procedure:**
  1. Place the metal rod on the heat-resistant mat.
  2. Carefully heat ONE end of the rod with the heat source.
  3. Observe how the heat travels along the rod (e.g., using touch carefully away from heat, thermal camera, or melting wax dots).
- **Safety:** Wear safety glasses. Handle hot rod with tongs. Be aware of hot surfaces.
- **Observation Prompt (for Worksheet 1):** Describe how the energy transferred from the hot end to the cold end. Explain using the particle model (vibrations, collisions). [N4]

Demo 2: Convection

- **Materials:** Large beaker or flask of water, heat source, (optional: potassium permanganate crystal or food colouring, small paper pieces).
- **Procedure (Option 1 - Visualisation):**
  1. Fill beaker with cold water. Carefully drop a small crystal of $KMnO4$ or a drop of food colouring to the bottom near one side.
  2. Gently heat the water directly below the colourant.
  3. Observe the movement of the coloured water.

- **Procedure (Option 2 - Simulation):** Use PhET "States of Matter" or search for "convection current simulation/video". Observe fluid movement patterns when heated from below.

- **Observation Prompt:** Describe the pattern of movement observed. Explain why the fluid moves in this way, relating it to temperature, density, and particle movement. [N4]

Demo 3: Radiation

- **Materials:** Heat lamp or incandescent bulb, hand or thermometer, (optional: infrared thermometer/camera).

- **Procedure:**

  1. Turn on the heat lamp/bulb.
  2. Carefully place a hand near (but not touching) the lamp. Feel the warmth.
  3. (Optional) Measure temperature near the lamp with IR thermometer or observe with IR camera.

- **Observation Prompt:** How did the heat reach your hand without direct contact or air movement being the main factor? What type of energy transfer is this? Does it require a medium? [N4]

Part B: PhET Simulation Exploration

Simulation: Energy Forms and Changes

- **Link:** https://phet.colorado.edu/en/simulations/energy-forms-and-changes

- **Procedure:**

  1. Open the simulation and select the "Intro" screen.
  2. Place a thermometer on the brick and the water.
  3. Place the brick and water on the stands.
  4. Check the "Energy Symbols" box.
  5. Use the slider to add heat to both the brick and the water.
  6. Observe:
     - The movement/vibration of the particles (atoms/molecules) within the brick and water.
     - The change in the temperature reading on the thermometers.
     - The flow of 'E' energy symbols representing heat transfer.

- **Observation Prompts (for Worksheet 1):**
  - How did particle motion change when heat was added? [N1]
  - How did temperature change? Relate particle motion to temperature. [N1]

Year 11 Physics - Worksheet 1
Thermodynamics: Particles, Temperature Energy Flow

Student Name: ________________________ ID: ______________

Module 3

Part 1: Defining Concepts (Knowledge Nodes N1, N4, N2)

1. **Define** the following terms precisely using your understanding from the lesson:
   - Thermodynamics:
   - Temperature (in terms of particle motion):
   - Thermal Energy:
   - Heat:
   - Conduction:
   - Convection:
   - Radiation (thermal):
   - Thermal Equilibrium:

[Literacy Focus: Precise scientific terminology - N1, N4, N2]

2. Using the particle model, **explain** why a metal spoon left in hot soup quickly becomes hot, while a wooden spoon takes much longer. Mention the key heat transfer mechanism involved. [N4 Understand]

3. Give one real-world **example** for each type of heat transfer where it is the *primary* mode of transfer:

- Conduction Example:
- Convection Example:
- Radiation Example:

[N4 Understand]

Part 2: Observations Explanations (Knowledge Nodes N1, N4)

4. From the PhET Simulation ("Energy Forms and Changes"):

- Describe what happened to the **motion** of the water/brick particles when heat energy was added. [N1 Understand]
- What happened to the **temperature** reading as heat was added? [N1 Understand]
- What is the relationship between the average kinetic energy of the particles and the temperature of the substance? [N1 Understand] *[Numeracy Focus: Qualitative interpretation of simulation*

  visuals - N1]

5. Consider the demonstrations of heat transfer:

- How does energy transfer differ fundamentally between conduction (e.g., metal rod) and radiation (e.g., heat lamp)? [N4 Understand]

#MarkSense Quiz 1

Instructions: Choose the best answer for multiple choice questions. Write brief answers for short answer questions in the space provided.

Student Name: ______________________ **ID:** ____________

1. Temperature is a measure of the ____ kinetic energy of particles in a substance. [N1]

A. Total

B. Average

C. Potential

D. Rotational

Answer: _____

2. Heat transfer through the movement of fluids (liquids/gases) is primarily: [N4]

A. Conduction

B. Convection

C. Radiation

D. Advection

Answer: _____

3. Explain why putting a lid on a hot cup of coffee keeps it warm longer, mentioning at least TWO heat transfer mechanisms. [N4, N2 conceptual link] (2 marks)

Lesson Pack Two

Year 11 Physics - Lesson Plan 2/3
Thermodynamics: Quantifying Heat Changing States

Philip Haynes

Based on NSW Stage 6 Syllabus (Module 3)

Lesson Overview

- **Lesson Title:** Measuring Heat: Specific Heat Capacity and Latent Heat
- **Duration:** 60 minutes
- **Focus Inquiry Question:** How are temperature, thermal energy, and particle motion related? (Specifically how energy input affects temperature vs. state).

Syllabus Alignment Knowledge Nodes Targeted

- **Outcomes:** PH11-10, PH11/12-4 (Processing Data), PH11/12-6 (Problem Solving), PH11/12-7 (Communicate)
- **Content:** ACSPH020, Investigate Latent Heat (Syllabus Focus)
- **Knowledge Nodes:** N3 (Specific Heat - Apply), N5 (Latent Heat - Analyse/Apply), links back to N1.

Student Learning Objectives (Aligned with Nodes)

Students will be able to:

- Analyse heat transfer quantitatively using Q=mcT (N3 - Apply).
- Analyse phase changes quantitatively using Q=mL (N5 - Analyse/Apply).
- Interpret heating/cooling curves quantitatively, linking sections to specific heat and latent heat (N5 - Analyse).
- Distinguish between the roles of specific heat capacity and latent heat in thermal processes.

Literacy: Define specific heat capacity (c), latent heat of fusion (Lf), latent heat of vaporization (Lv). Interpret and label phase change graphs accurately (N3, N5).

Numeracy: Calculate heat energy (Q) using Q=mcT and Q=mL. Analyse quantitative data from heating curves (N3, N5).

Lesson Structure & Activities

Introduction (10 mins)

- **Teacher Activity:** Review L1 concepts (Heat/Temp/KE). Pose prompt: "Why does beach sand get hotter than the ocean water under the same sun?" Guide discussion towards the idea that different substances require different amounts of heat for the same temperature change. Introduce Specific Heat Capacity 'c' [N3]. Present Q=mcT, focusing on the meaning and role of 'c'.

- **Student Activity:** Participate in recall and discussion. Record definition and concept of specific heat capacity (W/S 2). Understand the variables in Q=mcT.
- **Pedagogy Focus:** Retrieval Practice, Linking Concepts, Introducing Quantitative Parameter 'c' (N3).

Exploration (30 mins)

- **Teacher Activity:** Use PhET Simulation "States of Matter: Basics" (See Activity Sheet 2) to demonstrate heating ice through melting and boiling into steam. Project the Temp vs Energy/Time graph. Explicitly guide analysis of the graph: identify rising sections (specific heat) and flat sections (phase change). Ask guiding question: "Energy is being added, but temperature isn't rising. Why?" Introduce Latent Heat 'L' [N5 concept] - energy for changing state/bonds. Define Lf and Lv. Introduce Q=mL formula.
- **Student Activity:** Observe/interact with PhET simulation. Analyse the generated heating curve (guided by W/S 2 Part 1). Discuss the energy's role during phase changes (overcoming intermolecular forces). Record definitions for Lf, Lv, and Q=mL (W/S 2). [N5 Analyse]
- **Pedagogy Focus:** Data Analysis (Graphical N5), Visualisation (Micro/Macro link N1/N5), Guided Inquiry, Cognitive Science: Using simulations to make abstract concepts concrete.
- **ICT Integration:** PhET Simulation.
- **Numeracy Focus:** Interpreting slopes and plateaus on a quantitative graph (N5).

Consolidation (20 mins)

- **Teacher Activity:** Provide clear Worked Examples on board/slide: one using Q=mcT [N3 Apply], one using Q=mL [N5 Apply]. Assign practice calculation problems on Worksheet 2 (Part 2). Circulate to provide support. Distribute #MarkSense Quiz 2.
- **Student Activity:** Follow worked examples. Attempt practice problems on Worksheet 2, applying the correct formula based on the scenario (heating vs. phase change). Complete #MarkSense Quiz 2 (end of class or homework).
- **Pedagogy Focus:** Cognitive Load Management (Worked Examples), Application Practice (N3, N5 Apply), Formula Selection Skill.
- **Literacy Focus:** Translating word problems into required variables/formulae.
- **Numeracy Focus:** Accurate application of Q=mcT and Q=mL (N3, N5).

Resources Required

- Student laptops with internet access.
- PhET Simulation link (on Activity Sheet 2).
- Worksheet 2 (separate PDF).
- #MarkSense Quiz 2 (included on Worksheet 2 PDF).
- Data table with relevant specific heat (c) and latent heat (L) values (e.g., for water/ice/steam, common metals).
- Projector/Whiteboard.

Assessment

- **Formative:** Teacher observation during simulation analysis and problem-solving. Review of Worksheet 2 responses (graph analysis and calculations). Analysis of #MarkSense Quiz 2 results.

Differentiation

- **Support:** Provide partially completed worked examples. Allow use of calculators for all steps. Offer formula sheet with clear variable definitions.
- **Extension:** Include multi-step problems involving both specific and latent heat (e.g., ice below 0°C heated to steam above 100°C). Ask students to research Lf/Lv values for other substances and compare.

Thermodynamics Lesson 2: Quantifying Heat and Changing States

Mr Haynes

Gosford High School

April 8, 2025

Outline

Recap: Temperature and Heat Transfer

- Temperature measures average particle KE [N1].
- Heat is energy transferred due to ΔT.
- Mechanisms: Conduction, Convection, Radiation [N4].

Think/Pair/Share: Why does beach sand get much hotter than ocean water under the same sunlight?

Recap: Temperature and Heat Transfer

- Temperature measures average particle KE [N1].
- Heat is energy transferred due to ΔT.
- Mechanisms: Conduction, Convection, Radiation [N4].

Think/Pair/Share: Why does beach sand get much hotter than ocean water under the same sunlight?

- *Answer Hint:* Different substances require different amounts of energy to change temperature by the same amount.

Heating Up: Specific Heat Capacity

- **Definition:** The amount of heat energy required to raise the temperature of **1 kg** of a substance by **1 K** (or 1 °C).
- Symbol: c
- Units: $\mathrm{J\,kg^{-1}\,K^{-1}}$ or $\mathrm{J\,kg^{-1}\,{}^{\circ}C^{-1}}$
- **High 'c'** (like water: ≈ 4186): Takes a LOT of energy to heat up (and stores a lot).
- **Low 'c'** (like sand/metals: $\approx 800/400$): Heats up quickly with less energy.
- **Formula:** The heat energy (Q) needed for a temperature change (ΔT) depends on mass (m) and specific heat capacity (c):

$$Q = mc\Delta T$$

where $\Delta T = T_{final} - T_{initial}$.

Energy for Phase Changes: Latent Heat

Observation (Heating Curve): When a substance melts or boils, its temperature *remains constant* even though heat is being added. **Why?**

- Energy is used to overcome intermolecular forces (increase potential energy), not increase kinetic energy (temperature).

Definition: Latent heat (L) is the energy absorbed or released per unit mass during a phase change at constant temperature.

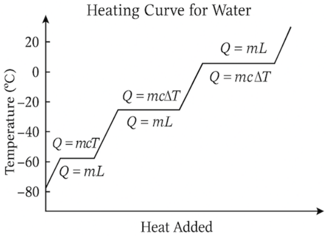
- **Latent Heat of Fusion (L_f):** Energy for solid $\leftrightarrow$ liquid change.
- **Latent Heat of Vaporization (L_v):** Energy for liquid $\leftrightarrow$ gas change. (Typically $L_v > L_f$)

Formula: Heat energy (Q) for phase change of mass (m):

$$Q = mL$$

(Use L_f for melting/freezing, L_v for boiling/condensing)

Putting It Together: The Heating Curve



Temperature vs Energy Added for Water

- **Sloped Sections:** Temperature changes. Energy increases particle KE. Use $Q = mc\Delta T$. (Specific Heat dominates).
- **Flat Sections (Plateaus):** Phase change occurs. Temperature constant. Energy increases particle PE (breaks bonds). Use $Q = mL$. (Latent Heat dominates).

Activity 2 uses PhET simulation to explore this.

Applying the Formulas

Example 1 (Specific Heat): Heat to warm 0.5 kg water from 10°C to 30°C? ($c_w = 4186$)

- $Q = mc\Delta T = (0.5)(4186)(30 - 10) = 41860\,\mathrm{J}$

Example 2 (Latent Heat): Heat to melt 0.1 kg ice at 0°C? ($L_{f,w} = 3.34 \times 10^5$)

- $Q = mL_f = (0.1)(3.34 \times 10^5) = 33400\,\mathrm{J}$

See Worksheet 2 for practice problems.

Lesson 2 Summary

- Specific Heat Capacity (c) relates heat added to temperature change ($Q = mc\Delta T$) [N3].
- Latent Heat (L) relates heat added to phase change ($Q = mL$) [N5].
- Heating curves show temperature changes (slopes) and phase changes (plateaus) [N5 Analyse].
- Energy added during phase change increases potential energy (breaks bonds), not kinetic energy (temperature).

Next Steps:

- Complete Worksheet 2 (Graph analysis, Calculations).
- Complete #MarkSense Quiz 2.
- Preview Lesson 3: Combining concepts in equilibrium problems, Efficiency.

Thank you!

Questions?

Year 11 Physics - Activity Sheet 2
Phase Changes & Heating Curves Simulation

Thermodynamics

Module 3 - Lesson 2

Aim

To use a simulation to observe the relationship between energy input, temperature, and phase changes for water, and to analyse the resulting heating curve quantitatively.

Knowledge Nodes Targeted

- N1: Temp/KE Relation (Revisited during heating phases)
- N3: Specific Heat (Analysing sloped sections of the graph)
- N5: Latent Heat (Analysing flat sections of the graph, understanding phase change energy)

ICT Resource: PhET Simulation

Simulation: States of Matter: Basics

- **Link:** https://phet.colorado.edu/en/simulations/states-of-matter-basics
- **Setup:**
  1. Open the simulation and select the "Phase Changes" screen.
  2. Select "Water" from the top right options.
  3. Observe the initial state (solid ice, likely below 0°C). Note the particle arrangement and motion.
  4. Ensure the thermometer units are set to Celsius (°C).

Procedure & Data Collection

- **Heating Process:**
  1. Begin adding heat using the slider at the bottom (move towards "Heat"). Try to add heat at a roughly constant rate.
  2. Observe the thermometer reading and the state/motion of the water molecules closely as heat is added.
  3. Continue adding heat until the water has turned into steam and its temperature is significantly above 100°C.
- **Observations to Focus On:**
  - At what temperatures does the phase change from solid to liquid (melting) occur?
  - At what temperatures does the phase change from liquid to gas (boiling) occur?

  - What happens to the temperature reading *during* melting?
  - What happens to the temperature reading *during* boiling?
  - What happens to the particle motion and arrangement during heating within a single phase (ice, water, or steam)?
  - What happens to the particle motion and arrangement *during* a phase change?

- **Data Analysis (for Worksheet 2 Part 1):**
  1. Sketch the shape of the Temperature vs. Time/Energy graph based on your observations.
  2. Label the different sections corresponding to heating the different phases and the phase changes themselves.
  3. Identify where energy input increases particle kinetic energy (temperature rises) and where it increases potential energy (breaks bonds during phase change).

Safety Notes

This is a computer simulation; no physical safety hazards are present.

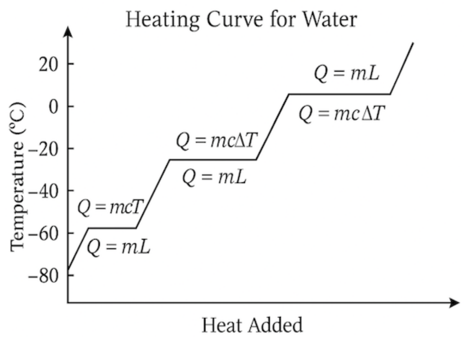
Year 11 Physics - Worksheet 2
Thermodynamics: Quantifying Heat Phase Change

Student Name: ________________________ ID: ______________

Module 3

Part 1: Heating Curve Analysis (Knowledge Node N5 Analyse)

1. The graph below shows a typical heating curve for water, starting as ice below 0°C and ending as steam above 100°C. Energy is added at a constant rate.



(a) On the graph above, clearly **label** the 5 sections corresponding to: Heating Ice, Melting Ice, Heating Water, Boiling Water, Heating Steam.

(b) In which section(s) is the added energy increasing the *kinetic energy* of the particles the most? **Explain** your reasoning.

(c) In which section(s) is the added energy primarily increasing the *potential energy* (overcoming bonds) of the particles? **Explain** your reasoning. [Literacy N5]

(d) Indicate on the graph where the formula Q=mcT would be used to calculate energy added, and where Q=mL would be used.

[Numeracy Focus: Graph interpretation - N5]

2. **Define** the following terms:

- Specific Heat Capacity (c):

- Latent Heat of Fusion (Lf):

- Latent Heat of Vaporization (Lv):

[Literacy N3, N5]

Part 2: Calculations (Knowledge Nodes N3 Apply, N5 Apply)

(Use the provided data table for c and L values)

Worked Example 1 (Q=mcT): Calculate heat needed to warm 200g (0.2kg) water from 20°C to 50°C. ($c_{water} = 4186\,\mathrm{J\,kg^{-1}\,K^{-1}}$) $Q = mc\Delta T = (0.2\,\mathrm{kg})(4186\,\mathrm{J\,kg^{-1}\,K^{-1}})(50 - 20\,\mathrm{K}) = 25116\,\mathrm{J}$

Worked Example 2 (Q=mL): Calculate heat needed to melt 50g (0.05kg) of ice at 0°C. ($L_{f,water} = 3.34 \times 10^5\,\mathrm{J\,kg^{-1}}$) $Q = mL_f = (0.05\,\mathrm{kg})(3.34 \times 10^5\,\mathrm{J\,kg^{-1}}) = 16700\,\mathrm{J}$

Practice Problems: Show your working clearly.

1. How much energy is released when 100g (0.1kg) of steam at 100°C condenses to water at 100°C? ($L_{v,water} = 2.26 \times 10^6\,\mathrm{J\,kg^{-1}}$) [N5 Apply]

2. Calculate the total heat required to change 30g (0.03kg) of ice at -15°C to water at 40°C. ($c_{ice} = 2100\,\mathrm{J\,kg^{-1}\,K^{-1}}$, $L_{f,water} = 3.34 \times 10^5\,\mathrm{J\,kg^{-1}}$, $c_{water} = 4186\,\mathrm{J\,kg^{-1}\,K^{-1}}$) [N3 Apply, N5 Apply] (Hint: This requires three steps: heating ice, melting ice, heating water). *[Numeracy Focus: Formula application, multi-step calculations - N3, N5]*

#MarkSense Quiz 2

Instructions: Choose the best answer for multiple choice questions. Show working for calculations.

Student Name: __________________________ **ID:** _______________

1. During boiling, the energy added is primarily used to: [N5]

A. Increase particle kinetic energy

B. Increase Temperature

C. Break intermolecular bonds / Increase potential energy

D. Decrease volume

Answer: _____

2. Substance A has a specific heat capacity of 900 J/kg°C and substance B has c=450 J/kg°C. If 1kg of each substance absorbs 900J of heat, which statement is true? [N3]

A. Temp of A increases by 1°C, Temp of B increases by 2°C.

B. Temp of A increases by 2°C, Temp of B increases by 1°C.

C. Both increase temperature by 1°C.

D. Both increase temperature by 2°C.

Answer: _____

3. Calculate the heat energy needed to raise the temperature of 500g (0.5kg) of water from 20°C to 60°C. ($c_{water} = 4186\,\mathrm{J\,kg^{-1}\,K^{-1}}$). Show working. [N3 Apply] (2 marks)

Lesson Pack Three

Year 11 Physics - Lesson Plan 3/3
Thermodynamics: Equilibrium Calculations Efficiency Concepts

Philip Haynes

Based on NSW Stage 6 Syllabus (Module 3)

Lesson Overview

- **Lesson Title:** Thermal Equilibrium Problems and Introduction to Efficiency
- **Duration:** 60 minutes
- **Focus Inquiry Question:** How are temperature, thermal energy, and particle motion related? (Application in equilibrium). What predicts and determines the direction and efficiency of energy transfer? (Equilibrium as predictor, Efficiency concept). How does energy transformation underpin the laws of thermodynamics? (Efficiency link to conservation/losses).

Syllabus Alignment Knowledge Nodes Targeted

- **Outcomes:** PH11-10, PH11/12-6 (Problem Solving), PH11/12-7 (Communicate)
- **Content:** ACSPH022 (Application)
- **Knowledge Nodes:** N2 (Thermal Equilibrium - Analyse/Apply), integrated application of N3 (Specific Heat) and N5 (Latent Heat). Conceptual links to N4 (Transfer Mechanisms) and Inquiry Q2/Q3 (Efficiency/Transformation).

Student Learning Objectives (Aligned with Nodes)

Students will be able to:

- Apply the principle of conservation of energy (Heat Lost = Heat Gained) to solve quantitative thermal equilibrium problems, potentially involving phase changes (N2 Analyse/Apply, N3 Apply, N5 Apply).
- Explain thermal efficiency conceptually (useful energy output / total energy input) and relate it to energy losses via heat transfer mechanisms (Links N4, Inquiry Q3).
- Conceptually link energy transformations and losses to thermodynamic principles (Links Inquiry Q2).

Literacy Justify the setup and steps in solving thermal equilibrium problems. Explain the concept of thermal efficiency and its relevance (N2, Inquiry Q3).

Numeracy Set up and solve multi-step algebraic equations involving Q=mcT and Q=mL in equilibrium scenarios (N2, N3, N5).

Lesson Structure & Activities

Introduction (10 mins)

- **Teacher Activity:** Review key formulae Q=mcT (N3) and Q=mL (N5) from L2. Revisit Thermal Equilibrium concept (N2). Explicitly state the energy conservation principle for isolated systems: Heat Lost by hotter object(s) = Heat Gained by colder object(s). Write equation form on board: $\Sigma Q_{lost} = \Sigma Q_{gained}$.
- **Student Activity:** Recall formulae and equilibrium concept. Understand the energy balance equation setup for equilibrium problems.
- **Pedagogy Focus:** Retrieval Practice, Establishing the core principle for complex problem solving (Conservation of Energy).

Exploration (25 mins)

- **Teacher Activity:** Lead a Guided Problem-Solving session for a thermal equilibrium calculation (e.g., hot metal in cold water - see Activity Sheet 3 / W/S 3 Part 1). Emphasise identifying initial states, final equilibrium state (Tf), and setting up the $Q_{lost} = Q_{gained}$ equation using appropriate N3/N5 formulae for each substance. Introduce Efficiency concept (Inquiry Q3): Use car engine/power plant example. Define qualitatively (Useful Out / Total In). Discuss why heat loss (via N4 mechanisms) prevents 100
- **Student Activity:** Follow guided problem steps on Worksheet 3 Part 1. Ask questions during the process. Participate in discussion on efficiency, identifying examples of energy input, useful output, and wasted heat output. [N2 Apply, N3 Apply]
- **Pedagogy Focus:** Guided Problem Solving (Cognitive Load Management for complex problems), Conceptual Breadth (Efficiency), Linking Concepts (N4 to Efficiency Losses), Contextualisation (Relevance).
- **Literacy Focus:** Explaining the setup of the conservation equation, defining efficiency.

Consolidation (25 mins)

- **Teacher Activity:** Assign 1-2 practice problems on Worksheet 3 (Part 2) involving thermal equilibrium, potentially including phase changes [N5 integration]. Encourage students to work in pairs (Collaborative Learning). Circulate, offering targeted support. Briefly review how the three lessons addressed the main Inquiry Questions. Distribute #MarkSense Quiz 3.
- **Student Activity:** Work collaboratively or individually on practice problems (W/S 3 Part 2). Seek help if needed. Reflect on Inquiry Question connections. Complete #MarkSense Quiz 3 (end of class or homework). [N2 Apply, N3 Apply, N5 Apply]
- **Pedagogy Focus:** Collaborative/Independent Practice, Application of multiple concepts (N2, N3, N5), Synthesis (Linking back to Inquiry Qs), Formative Assessment.
- **Numeracy Focus:** Solving multi-step equilibrium problems possibly involving phase change calculations (N2, N3, N5).

Resources Required

- Worksheet 3 (separate PDF).
- #MarkSense Quiz 3 (included on Worksheet 3 PDF).
- Data table with relevant specific heat (c) and latent heat (L) values.

- Calculators.
- Projector/Whiteboard.

Assessment

- **Formative:** Teacher observation during collaborative problem-solving. Review of Worksheet 3 problem-solving approaches and answers. Analysis of #MarkSense Quiz 3 results.

Differentiation

- **Support:** Provide pre-structured templates for setting up equilibrium equations (Q_{lost} side = Q_{gained} side). Focus practice on problems without phase changes initially.
- **Extension:** Include problems with multiple substances mixing, or where heat loss to the container (calorimeter) must be considered. Challenge students to research the thermodynamic efficiency of different types of power plants.

Thermodynamics Lesson 3: Equilibrium Calculations and Efficiency

Mr Haynes

Gosford High School

April 7, 2025

Outline

Recap: Quantifying Heat

Quick Quiz: Match the scenario to the formula!

- Heating 1kg water from 20°C to 80°C $\implies$ Use ____________ [N3]
- Melting 0.5kg ice at 0°C $\implies$ Use ____________ [N5]
- Cooling 2kg steam at 120°C to 110°C $\implies$ Use ____________ [N3]
- Boiling 0.2kg water at 100°C $\implies$ Use ____________ [N5]

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- Boiling 0.2kg water at 100°C $\implies$ Use __________ [N5]

Answers: $Q{=}mc\Delta T$, $Q{=}mL_f$, $Q{=}mc\Delta T$, $Q{=}mL_v$ Today: Combining

these when things mix and reach equilibrium.

Principle of Thermal Equilibrium Problems

Scenario: Mix hot and cold substances in an *isolated* system (no heat loss to surroundings). **Principle (Conservation of Energy):**

- Heat energy flows from hotter object(s) to colder object(s).
- Flow stops when thermal equilibrium (same final temperature T_f) is reached.
- Total heat energy **lost** by hot objects = Total heat energy **gained** by cold objects.

$$\sum Q_{lost} = \sum Q_{gained}$$

Each 'Q' term could involve $mc\Delta T$ or mL depending on temperature changes and phase changes.

Guided Example: Hot Metal in Cold Water

(Refer to Worksheet 3, Part 1 for step-by-step guidance) **Problem:** 50g

Copper ($c_{Cu} = 385$) at 90°C dropped into 100g Water ($c_w = 4186$) at 15°C. Find final temp (T_f). **Setup:**

- Identify Hot (Cu) / Cold (Water).
- $Q_{lost,Cu} = Q_{gained,w}$
- $(mc\Delta T)_{Cu} = (mc\Delta T)_w$
- $m_{Cu}c_{Cu}(T_{i,Cu} - T_f) = m_w c_w(T_f - T_{i,w})$

Key Steps (Teacher demonstrates on board):

1. Substitute values (ensure mass in kg if needed, though g cancels if consistent).
2. Expand brackets carefully.
3. Group T_f terms on one side.
4. Solve for T_f.

[Numeracy focus: Algebraic manipulation]

Introduction to Thermal Efficiency

Energy Transformations (Inquiry Q2): Energy is conserved, but changes form. **Think about a Car Engine:**

- **Energy Input:** Chemical Energy in Fuel
- **Useful Energy Output:** Kinetic Energy (Motion)
- **Wasted Energy Output:** Heat (Exhaust, Friction, Engine Block heating -> lost via Conduction/Convection/Radiation [N4 link])

Thermal Efficiency (Qualitative Definition):

$$\text{Efficiency} = \frac{\text{Useful Energy Output}}{\text{Total Energy Input}}$$

- Always less than 1 (or 100%). Why? Some energy is always "lost" as less useful thermal energy during transformations (related to the 2nd Law of Thermodynamics).
- **Relevance (Inquiry Q3):** Understanding losses helps improve efficiency (e.g., insulation, better engine design) $\Longrightarrow$ Sustainability.

Applying Equilibrium Principles

Now, try the problems in Worksheet 3, Part 2.

- Work individually or in pairs.
- Problem 1: Similar to guided example (metal in water).
- Problem 2: Challenge involving phase change (melting ice). Remember to include $Q = mL_f$ for the ice melting!

Connecting back to Inquiry Questions:

- Q1 (Temp/Energy/Motion): Underpins all calculations.
- Q2 (Transformation/Laws): Efficiency shows energy changes form, conservation applies.
- Q3 (Direction/Efficiency): Equilibrium determines direction, efficiency measures usefulness.

Lesson 3 Summary

- Thermal equilibrium problems are solved using Conservation of Energy: $\sum Q_{lost} = \sum Q_{gained}$ [N2 Apply].
- These problems combine specific heat ($mc\Delta T$) [N3] and potentially latent heat (mL) [N5] calculations.
- Thermal efficiency describes how effectively input energy is converted to useful output energy [Inquiry Q3].
- Understanding heat transfer mechanisms [N4] is key to understanding energy losses and efficiency.

Final Steps:

- Complete Worksheet 3 Practice Problems.
- Complete #MarkSense Quiz 3.
- Review all concepts from the 3 lessons.

Thank you!

End of Thermodynamics Introduction. Questions?

Year 11 Physics - Activity Sheet 3
Thermal Equilibrium Calculations

Thermodynamics

Module 3 - Lesson 3

Aim

To apply the principle of conservation of energy ($Q_{lost} = Q_{gained}$) to solve problems involving thermal equilibrium between substances, incorporating specific heat capacity and potentially latent heat.

Knowledge Nodes Targeted

- N2: Thermal Equilibrium (Applying the concept quantitatively)
- N3: Specific Heat (Used within equilibrium calculations)
- N5: Latent Heat (Used within equilibrium calculations involving phase change)

Activity: Guided and Practice Problem Solving

This activity focuses on applying the concepts learned in Lessons 1 and 2 to quantitative problems. The main tool is the principle of energy conservation in an isolated system.

Core Principle

In an isolated system where hotter and colder substances are mixed, heat energy will transfer from the hotter substance(s) to the colder substance(s) until thermal equilibrium is reached (i.e., they reach the same final temperature, T_f). The total energy lost by the initially hotter substance(s) must equal the total energy gained by the initially colder substance(s).

$$\sum Q_{lost} = \sum Q_{gained}$$

Where Q can be calculated using $Q = mc\Delta T$ for temperature changes and $Q = mL$ for phase changes. Remember:

- For heat loss: $\Delta T = T_{initial,hot} - T_{final}$
- For heat gain: $\Delta T = T_{final} - T_{initial,cold}$
- Phase change energy must be included if a substance melts/freezes or boils/condenses during the process.

Guided Problem (Refer to Worksheet 3 Part 1)

The teacher will guide the class through solving the problem of mixing hot copper with cold water, demonstrating the setup and algebraic solution for the final equilibrium temperature (T_f).

Practice Problems (Refer to Worksheet 3 Part 2)

Students will work individually or in pairs to solve the practice problems provided on the worksheet. These problems may involve:

- Mixing two substances with no phase change (applying $Q = mc\Delta T$ on both sides).
- Mixing substances where one undergoes a phase change (applying $Q = mL$ and $Q = mc\Delta T$ as needed).

Required Data

A data table with specific heat capacities (c) and latent heats (L) for relevant materials (e.g., water, ice, steam, copper, lead, aluminium) is required. (This should be provided with Worksheet 3 or displayed).

Numeracy Focus

- Setting up algebraic equations based on the energy conservation principle.
- Correctly identifying terms for heat loss and heat gain.
- Accurately substituting values (including unit consistency, e.g., mass in kg if 'c' or 'L' are per kg).
- Solving the resulting algebraic equations for the unknown variable (often T_f or an unknown mass).

Literacy Focus

- Clearly justifying the steps taken in the problem-solving process.
- Explaining the meaning of the energy conservation equation in the context of the problem.

Year 11 Physics - Worksheet 3
Thermodynamics: Equilibrium Efficiency

Student Name: ________________________ ID: ______________

Module 3

Part 1: Equilibrium Problem Solving (Knowledge Nodes N2 Apply, N3 Apply)

1. State the principle of energy conservation applied when calculating the final temperature of a mixture in an isolated system. [N2 Concept]

2. **Guided Problem:** Calculate the final equilibrium temperature (T_f) when 50g (0.05kg) of copper ($c_{Cu} = 385\,\mathrm{J\,kg^{-1}\,K^{-1}}$) initially at 90°C is placed into 100g (0.1kg) of water ($c_{water} = 4186\,\mathrm{J\,kg^{-1}\,K^{-1}}$) initially at 15°C. Assume no heat loss to the surroundings.

Step 1: Identify the hotter object (loses heat) and colder object (gains heat). Hotter: Copper (Cu) at $T_{i,Cu} = 90°\mathrm{C}$ Colder: Water (w) at $T_{i,w} = 15°\mathrm{C}$

Step 2: Write the energy conservation equation: $Q_{lost,Cu} = Q_{gained,w}$

Step 3: Substitute the formula $Q = mc\Delta T$ for each side. Remember ΔT is always positive change, so for the losing side, $\Delta T = T_{initial} - T_{final}$, and for the gaining side, $\Delta T = T_{final} - T_{initial}$. $(mc\Delta T)_{Cu} = (mc\Delta T)_w$ $(m_{Cu})(c_{Cu})(T_{i,Cu} - T_f) = (m_w)(c_w)(T_f - T_{i,w})$

Step 4: Substitute known values. $(0.05)(385)(90 - T_f) = (0.1)(4186)(T_f - 15)$

Step 5: Solve algebraically for T_f. Show your working below. [Numeracy N2, N3] Final Temperature

$T_f =$ __________ °C

Part 2: Practice Problems Concepts (N2, N3, N5, Inquiry Q3)

(Use the provided data table for c and L values)

1. Calculate the final equilibrium temperature if 200g (0.2kg) of lead ($c_{Pb} = 128\,\mathrm{J\,kg^{-1}\,K^{-1}}$) at 100°C is mixed with 100g (0.1kg) of water ($c_w = 4186\,\mathrm{J\,kg^{-1}\,K^{-1}}$) at 25°C. Assume no heat loss. [N2 Apply, N3 Apply]

2. **Challenge Problem:** How much ice at 0°C must be added to 400g (0.4kg) of water at 60°C to lower the final mixture temperature to exactly 10°C? ($L_{f,water} = 3.34 \times 10^5\,\mathrm{J\,kg^{-1}}$, $c_{water} = 4186\,\mathrm{J\,kg^{-1}\,K^{-1}}$) [N2 Apply, N3 Apply, N5 Apply] (Hint: The ice melts first, then the resulting water warms up. The original water cools down. $Q_{lost} = Q_{gained,melting} + Q_{gained,warming\_melted\_ice}$)

3. Define Thermal Efficiency qualitatively (in terms of energy input and useful energy output). Give ONE reason why waste heat is always produced in practical energy conversions (e.g., in a car engine). [Literacy Inquiry Q3]

#MarkSense Quiz 3

Instructions: Choose the best answer for multiple choice questions. Show working for calculations.

Student Name: ___________________________ **ID:** ________________

1. Thermal equilibrium between two objects in contact is reached when: [N2]

A. Their masses are equal.

B. Their total thermal energies are equal.

C. There is no net flow of heat between them.

D. One object has lost all its heat.

Answer: _____

2. If a highly efficient machine converts 100J of input energy into 40J of useful work, how much energy was wasted, likely as heat? [Inquiry Q3 Concept]

A. 40 J

B. 60 J

C. 100 J

D. 140 J

Answer: _____

3. 50g of Metal X ($c = 500\,\mathrm{J\,kg^{-1}\,K^{-1}}$) at 100°C is dropped into 100g of Water ($c = 4186\,\mathrm{J\,kg^{-1}\,K^{-1}}$) at 20°C. Set up the equation $Q_{lost} = Q_{gained}$ that you would use to find the final temperature (T_f). Do NOT solve it. (2 marks) [N2 Apply, N3 Apply]