Topic 5: Energetics/thermochemistry

9 hours

Essential idea: The enthalpy changes from chemical reactions can be calculated from their effect on the temperature of their surroundings.

5.1 Measuring energy changes

Nature of science:

Fundamental principle—conservation of energy is a fundamental principle of science. (2.6)

Making careful observations—measurable energy transfers between systems and surroundings. (3.1)

Understandings:

- Heat is a form of energy.
- Temperature is a measure of the average kinetic energy of the particles.
- Total energy is conserved in chemical reactions.
- Chemical reactions that involve transfer of heat between the system and the surroundings are described as endothermic or exothermic.
- The enthalpy change (ΔH) for chemical reactions is indicated in kJ mol^{-1}.
- ΔH values are usually expressed under standard conditions, given by $\Delta H°$, including standard states.

Applications and skills:

- Calculation of the heat change when the temperature of a pure substance is changed using $q = mc\Delta T$.
- A calorimetry experiment for an enthalpy of reaction should be covered and the results evaluated.

Guidance:

- Enthalpy changes of combustion (ΔH_c°) and formation (ΔH_f°)should be covered.
- Consider reactions in aqueous solution and combustion reactions.

International-mindedness:

- The SI unit of temperature is the Kelvin (K), but the Celsius scale (°C), which has the same incremental scaling, is commonly used in most countries. The exception is the USA which continues to use the Fahrenheit scale (°F) for all non-scientific communication.

Theory of knowledge:

- What criteria do we use in judging discrepancies between experimental and theoretical values? Which ways of knowing do we use when assessing experimental limitations and theoretical assumptions?

Utilization:

- Determining energy content of important substances in food and fuels.

Syllabus and cross-curricular links:
Topic 1.1—conservation of mass, changes of state
Topic 1.2—the mole concept

Aims:

- **Aim 6**: Experiments could include calculating enthalpy changes from given experimental data (energy content of food, enthalpy of melting of ice or the enthalpy change of simple reactions in aqueous solution).
- **Aim 7**: Use of databases to analyse the energy content of food.
- **Aim 7**: Use of data loggers to record temperature changes.

5.1 Measuring energy changes	
• Standard state refers to the normal, most pure stable state of a substance measured at 100 kPa. Temperature is not a part of the definition of standard state, but 298 K is commonly given as the temperature of interest. • The specific heat capacity of water is provided in the data booklet in section 2. • Students can assume the density and specific heat capacities of aqueous solutions are equal to those of water, but should be aware of this limitation. • Heat losses to the environment and the heat capacity of the calorimeter in experiments should be considered, but the use of a bomb calorimeter is not required.	

Essential idea: In chemical transformations energy can neither be created nor destroyed (the first law of thermodynamics).

5.2 Hess's Law

Nature of science:

Hypotheses—based on the conservation of energy and atomic theory, scientists can test the hypothesis that if the same products are formed from the same initial reactants then the energy change should be the same regardless of the number of steps. (2.4)

Understandings:

- The enthalpy change for a reaction that is carried out in a series of steps is equal to the sum of the enthalpy changes for the individual steps.

Applications and skills:

- Application of Hess's Law to calculate enthalpy changes.
- Calculation of ΔH reactions using ΔH_f° data.
- Determination of the enthalpy change of a reaction that is the sum of multiple reactions with known enthalpy changes.

Guidance:

- Enthalpy of formation data can be found in the data booklet in section 12.
- An application of Hess's Law is $\Delta H \text{ reaction} = \Sigma(\Delta H_f^\circ \text{products}) - \Sigma(\Delta H_f^\circ \text{reactants})$.

International-mindedness:

- Recycling of materials is often an effective means of reducing the environmental impact of production, but varies in its efficiency in energy terms in different countries.

Theory of knowledge:

- Hess's Law is an example of the application of the Conservation of Energy. What are the challenges and limitations of applying general principles to specific instances?

Utilization:

- Hess's Law has significance in the study of nutrition, drugs, and Gibbs free energy where direct synthesis from constituent elements is not possible.

Syllabus and cross-curricular links:
Physics topic 2.3—conservation of mass-energy

Aims:

- **Aim 4**: Discuss the source of accepted values and use this idea to critique experiments.
- **Aim 6**: Experiments could include Hess's Law labs.
- **Aim 7**: Use of data loggers to record temperature changes.

Essential idea: Energy is absorbed when bonds are broken and is released when bonds are formed.

5.3 Bond enthalpies

Nature of science:

Models and theories—measured energy changes can be explained based on the model of bonds broken and bonds formed. Since these explanations are based on a model, agreement with empirical data depends on the sophistication of the model and data obtained can be used to modify theories where appropriate. (2.2)

Understandings:

- Bond-forming releases energy and bond-breaking requires energy.
- Average bond enthalpy is the energy needed to break one mol of a bond in a gaseous molecule averaged over similar compounds.

Applications and skills:

- Calculation of the enthalpy changes from known bond enthalpy values and comparison of these to experimentally measured values.
- Sketching and evaluation of potential energy profiles in determining whether reactants or products are more stable and if the reaction is exothermic or endothermic.
- Discussion of the bond strength in ozone relative to oxygen in its importance to the atmosphere.

Guidance:

- Bond enthalpy values are given in the data booklet in section 11.
- Average bond enthalpies are only valid for gases and calculations involving bond enthalpies may be inaccurate because they do not take into account intermolecular forces.

International-mindedness:

- Stratospheric ozone depletion is a particular concern in the polar regions of the planet, although the pollution that causes it comes from a variety of regions and sources. International action and cooperation have helped to ameliorate the ozone depletion problem.

Utilization:

- Energy sources, such as combustion of fossil fuels, require high ΔH values.

Syllabus and cross-curricular links:
Topic 4.3—covalent structures

Aims:

- **Aim 6**: Experiments could be enthalpy of combustion of propane or butane.
- **Aim 7**: Data loggers can be used to record temperature changes.
- **Aim 8**: Moral, ethical, social, economic and environmental consequences of ozone depletion and its causes.