Topic 1: Measurement and uncertainties

5 hours

Essential idea: Since 1948, the Système International d'Unités (SI) has been used as the preferred language of science and technology across the globe and reflects current best measurement practice.

1.1 – Measurements in physics

Nature of science:

Common terminology: Since the 18th century, scientists have sought to establish common systems of measurements to facilitate international collaboration across science disciplines and ensure replication and comparability of experimental findings. (1.6)

Improvement in instrumentation: An improvement in apparatus and instrumentation, such as using the transition of cesium-133 atoms for atomic clocks, has led to more refined definitions of standard units. (1.8)

Certainty: Although scientists are perceived as working towards finding "exact" answers, the unavoidable uncertainty in any measurement always exists. (3.6)

Understandings:

- Fundamental and derived SI units
- Scientific notation and metric multipliers
- Significant figures
- Orders of magnitude
- Estimation

International-mindedness:

- Scientific collaboration is able to be truly global without the restrictions of national borders or language due to the agreed standards for data representation

Theory of knowledge:

- What has influenced the common language used in science? To what extent does having a common standard approach to measurement facilitate the sharing of knowledge in physics?

1.1 – Measurements in physics	
Applications and skills: • Using SI units in the correct format for all required measurements, final answers to calculations and presentation of raw and processed data • Using scientific notation and metric multipliers • Quoting and comparing ratios, values and approximations to the nearest order of magnitude • Estimating quantities to an appropriate number of significant figures **Guidance:** • SI unit usage and information can be found at the website of *Bureau International des Poids et Mesures* • Students will not need to know the definition of SI units except where explicitly stated in the relevant topics in this guide • Candela is not a required SI unit for this course • Guidance on any use of non-SI units such as eV, MeV c^{-2}, ly and pc will be provided in the relevant topics in this guide • Further guidance on how scientific notation and significant figures are used in examinations can be found in the *Teacher support material* **Data booklet reference:** • Metric (SI) multipliers can be found on page 5 of the physics data booklet	**Utilization:** • This topic is able to be integrated into any topic taught at the start of the course and is important to all topics • Students studying more than one group 4 subject will be able to use these skills across all subjects • See *Mathematical studies SL* sub-topics *1.2–1.4* **Aims:** • **Aim 2 and 3:** this is an essential area of knowledge that allows scientists to collaborate across the globe • **Aim 4 and 5:** a common approach to expressing results of analysis, evaluation and synthesis of scientific information enables greater sharing and collaboration

Essential idea: Scientists aim towards designing experiments that can give a "true value" from their measurements, but due to the limited precision in measuring devices, they often quote their results with some form of uncertainty.

1.2 – Uncertainties and errors

Nature of science:

Uncertainties: "All scientific knowledge is uncertain… if you have made up your mind already, you might not solve it. When the scientist tells you he does not know the answer, he is an ignorant man. When he tells you he has a hunch about how it is going to work, he is uncertain about it. When he is pretty sure of how it is going to work, and he tells you, 'This is the way it's going to work, I'll bet,' he still is in some doubt. And it is of paramount importance, in order to make progress, that we recognize this ignorance and this doubt. Because we have the doubt, we then propose looking in new directions for new ideas." (3.4)

Feynman, Richard P. 1998. *The Meaning of It All: Thoughts of a Citizen-Scientist*. Reading, Massachusetts, USA. Perseus. P 13.

Understandings:

- Random and systematic errors
- Absolute, fractional and percentage uncertainties
- Error bars
- Uncertainty of gradient and intercepts

Applications and skills:

- Explaining how random and systematic errors can be identified and reduced
- Collecting data that include absolute and/or fractional uncertainties and stating these as an uncertainty range (expressed as: best estimate ± uncertainty range)
- Propagating uncertainties through calculations involving addition, subtraction, multiplication, division and raising to a power
- Determining the uncertainty in gradients and intercepts

Theory of knowledge:

- "One aim of the physical sciences has been to give an exact picture of the material world. One achievement of physics in the twentieth century has been to prove that this aim is unattainable." – Jacob Bronowski. Can scientists ever be truly certain of their discoveries?

Utilization:

- Students studying more than one group 4 subject will be able to use these skills across all subjects

1.2 – Uncertainties and errors	
Guidance: • Analysis of uncertainties will not be expected for trigonometric or logarithmic functions in examinations • Further guidance on how uncertainties, error bars and lines of best fit are used in examinations can be found in the *Teacher support material* **Data booklet reference:** • If $y = a \pm b$ then $\Delta y = \Delta a + \Delta b$ • If $y = \frac{ab}{c}$ then $\frac{\Delta y}{y} = \frac{\Delta a}{a} + \frac{\Delta b}{b} + \frac{\Delta c}{c}$ • If $y = a^n$ then $\frac{\Delta y}{y} = \left\| n\frac{\Delta a}{a} \right\|$	**Aims:** • **Aim 4:** it is important that students see scientific errors and uncertainties not only as the range of possible answers but as an integral part of the scientific process • **Aim 9:** the process of using uncertainties in classical physics can be compared to the view of uncertainties in modern (and particularly quantum) physics

Essential idea: Some quantities have direction and magnitude, others have magnitude only, and this understanding is the key to correct manipulation of quantities. This sub-topic will have broad applications across multiple fields within physics and other sciences.

<table>
<tr><th colspan="2">1.3 – Vectors and scalars</th></tr>
<tr><td colspan="2">Nature of science:

Models: First mentioned explicitly in a scientific paper in 1846, scalars and vectors reflected the work of scientists and mathematicians across the globe for over 300 years on representing measurements in three-dimensional space. (1.10)</td></tr>
<tr><td>Understandings:
• Vector and scalar quantities
• Combination and resolution of vectors
Applications and skills:
• Solving vector problems graphically and algebraically
Guidance:
• Resolution of vectors will be limited to two perpendicular directions
• Problems will be limited to addition and subtraction of vectors and the multiplication and division of vectors by scalars</td><td>International-mindedness:
• Vector notation forms the basis of mapping across the globe
Theory of knowledge:
• What is the nature of certainty and proof in mathematics?
Utilization:
• Navigation and surveying (see Geography SL/HL syllabus: Geographic skills)
• Force and field strength (see Physics sub-topics 2.2, 5.1, 6.1 and 10.1)
• Vectors (see Mathematics HL sub-topic 4.1; Mathematics SL sub-topic 4.1)</td></tr>
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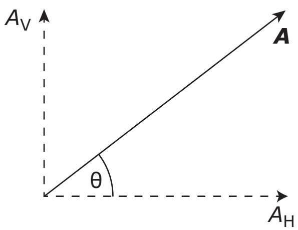
1.3 – Vectors and scalars	
Data booklet reference:  • $A_H = A\cos\theta$ • $A_v = A\sin\theta$	**Aims:** • **Aim 2 and 3:** this is a fundamental aspect of scientific language that allows for spatial representation and manipulation of abstract concepts