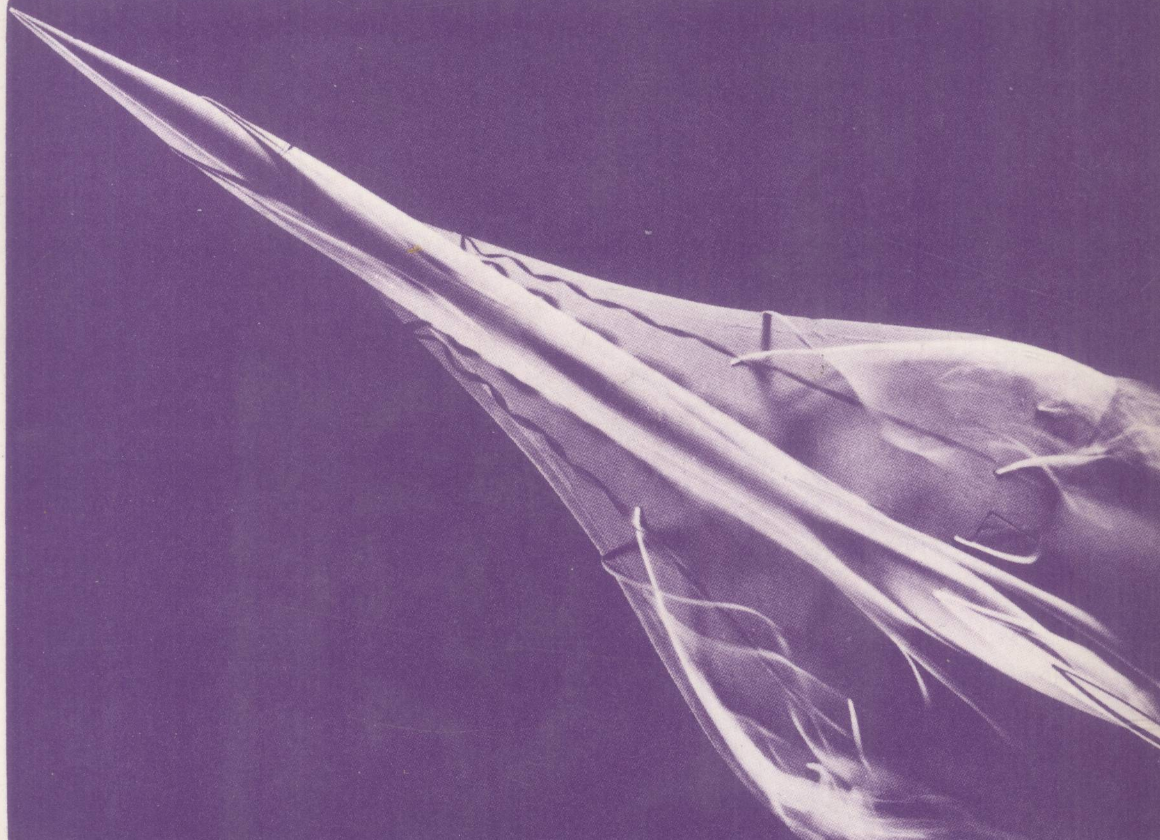
New Certificate Physics for Hong Kong



Harvey Johnson

New Certificate Physics for Hong Kong

Harvey Johnson

Heinemann Educational Books (Asia) Ltd
Hong Kong Singapore Kuala Lumpur

HEINEMANN EDUCATIONAL BOOKS (ASIA) LTD

Yik Yin Building, 231-3 To Kwa Wan Road, Kowloon,
Hong Kong.
41 Jalan Pemimpin, Singapore 20
No. 2, Jalan 20/16A, Paramount Garden,
Petaling Jaya, Selangor, Malaysia.

Heinemann Educational Books Ltd., London
Associated companies, branches &
representatives throughout the world

Printed in Hong Kong by
Po Fung Printing Co.

New Certificate Physics for Hong Kong

Harvey Johnson

Preface

This book is designed to meet all the basic textbook requirements for a complete course leading to the Certificate of Education Examination in Physics. Subject matter, order of presentation, approaches, depth of treatment and questions are all based on the recommendations of the Hong Kong Curriculum Development Committee. Starting points are based on the Physics content of the three-year Integrated Science Course. At the same time, some care has been taken to ensure that all the essential subject matter is contained in this one book.

Why Study Physics? Students are, very naturally, concerned about examination success. As a result, they often lose sight of the reasons *why* a subject like Physics is studied. The reasons are that Physics is tremendously *useful*, and Physics can be immensely *interesting* and *exciting*.

How to Study Physics? One method, tried by generations of students (mostly unsuccessful), is that 'super-memory' approach. This means treating the subject as a large number of facts, theories and methods to be memorized and (hopefully) repeated in the examination. Also, of course, to be forgotten immediately after the examination! Really, a waste of time.

The right approach is to be continually involved in the learning process. We all learn best by doing, so an understanding of experimental techniques comes from actually performing experiments. Theories come from facts obtained by experiment and observation. Take an active part in building any new theory, making sure that you understand how it arises from the facts. Continually check that you *understand* theories and techniques. The best way to do this, of course, is to try to apply them, and the easiest method of doing this is to solve related problems. For this reason, you should always try to solve the Problems given within each Section, *before* looking at the solutions. Never be content to treat something as being isolated from the rest of the subject. Always try to see how it relates to the important central ideas like energy, particle nature of matter, wave nature and behaviour of electrical charges. Really, the subject is made up of a few key techniques and ideas, applied in a large number of different situations.

The newspapers often contain reports of scientific interest. And there are a wide variety of science-based periodicals. Read what is interesting and the subject itself becomes more interesting.

Summarizing: Successful study is based on

1. taking an active part in experimental investigation, development of ideas and theories.
2. continually checking understanding by problem-solving.
3. continually looking for essential links between parts of the subject
4. treating physics as a major human activity and, when possible, doing some related general reading.

Harvey Johnson

Acknowledgements

Acknowledgements for permission to publish photographs are due as follows:

Dr. C. Jonsson A.27(b);
Harvard Project Physics A.10, A.15, A.17(b), A.19(b), A.20, A.25(b), A.27(b);
Jim Jardine A.7(b), A.13(a), B.22, B.29(c), B.44, B.50, C.27, C.33, H.27, H.28;
The National Physical Laboratory E.23(b);
United Kingdom Atomic Energy Authority I.19.

Contents

Preface
Acknowledgement
Introduction 1
Section A Waves 11
1. Vibrations and Waves
2. Water Waves
3. The Nature of Light
4. Electromagnetic Waves

Section B Optics 55
1. Reflection
2. Refraction, Lenses and Optical Instruments
3. Total Internal Reflection

Section C Mechanics I 107
1. Motion: Displacement, Velocity and Acceleration
2. Force: The agent of changes in Motion

Section D Heat I 157
1. The Nature of Heat and Matter: Kinetic Theory
2. Gases: Models and Laws

Section E Electricity I 175
1. Charges at Rest: Electrostatics
2. Charges in Motion: Simple Electrical Circuits
3. Magnetic Effects of Electric Currents

Section F Mechanics II 233
1. Gravitation
2. Forces and Momentum
3. Mechanical Energy and Work
4. Doing Useful Work: Simple Machines

Section G Heat II 279
1. Measuring Heat Energy
2. Thermometry
3. Heat and Changes of State

Section H Electricity II 309
1. Electromagnetic Induction and Domestic Electricty
2. Electronics

Section I The Atom 349
Section J Examination Techniques and Further Questions 379
Index 409

Introduction

OBSERVATION AND MEASUREMENT

The subject we call Physics is based on **facts**. What *is* a fact? In any science, a fact arises from direct observation. If I make an observation that hanging a weight from a spiral spring causes the spring to get longer, I can state this as a fact. The fact becomes acceptable if someone else does the same experiment and the results obtained are the same.

In other words, information can only be described as a fact if it has been obtained from an observation and the observation can be checked by someone else.

The most useful observations are those which tell us how large something is. In everyday language, you would probably accept a statement like "I saw a big rat on the deck of the small ship" without question. You know that the speaker means that the rat was larger than the average for rats and that the ship was small compared to most ships. In other words, you both used some *standard* of comparison. In science rough standards of this kind are of very limited use. When different scientists in different countries talk about 'how large', they must both use the same standard of comparison. **Measurement** of a quantity always involves comparison with a standard of that quantity. After measurements, the rat might be described in terms like:

Length from nose to tail = 40 cm (or 0.4 m)
Mass = 350 g (or 0.35 kg)

Of course, there is more than one quantity which can be used to describe the size of something. Fortunately, we can reduce all our measurements to only five basic quantities:

Mass (m), Length (l), Time (t), Electric current (I), Temperature (θ). For each quantity, there is a **unit.** (See table one). Other quantities and units are derived from these five.

SOME SIMPLE PRINCIPLES OF MEASUREMENT

Reading scales: Always look vertically down on the scale (and if used), the pointer.
Sensitivity: This is indicated by the smallest division on a scale. For example:
a micrometer reading of 0.41 mm is sensitive to 0.01 mm
a metre rule reading of 401 mm is sensitive to 1 mm
The first reading is therefore 100 times more sensitive than the second
Accuracy: One of the commonest mistakes made by physics students is to assume that accuracy and sensitivity are measurments of the same thing. They are not! At the same time, the accuracy of a reading *can* be increased by increasing the sensitivity.

The accuracy of a reading is controlled by two things:

(a) The **possible error** in reading, which depends on the sensitivity of the scale. The micrometer reading above has a possible error of 0.01 mm. The metre rule reading has a possible error of 1 mm

(b) The **size of the quantity** being measured. In our two examples, the sizes are 0.41 mm and 401 mm.

Putting these together, the possible *percentage error* is given by

$$\text{possible percentage error} = \frac{\text{possible error}}{\text{size of reading}} \times 100\ \%$$

The *smaller* this value is, the *greater* the accuracy.

Going back to our examples

Measurement 1	Measurement 2
$\%\ \text{error} = \frac{1}{40} \times 100$	$\%\ \text{error} = \frac{1}{400} \times 100$
$= 2.5\%$	$= 0.25\%$

This means that the percentage error in the micrometer reading is ten times greater than the percentage error in the metre rule reading; i.e. for *these* measurements, the metre rule reading is more accurate, so the more sensitive reading gives a smaller accuracy.

Here is another example:

The circumference of the earth is measured and found to be 40 000 km. Assuming the measurement is made to the nearest km, what is the percentage error?

$$\%\ \text{error} = \frac{\text{possible error}}{\text{reading}} \times 100\%$$

$$= \frac{1}{40\ 000} \times 100$$

$$= 0.002\ 5\ \%$$

This reading is very much more accurate than either of the two previous examples, even though the possible reading error is many time greater!

The lesson we learn from this is that very sensitive reading instruments are needed only when the quantity to be measured is very small.

Sensible Numerical Values: Every measurement you make has a possible error. This is partly due to the fact that no person is perfect and partly due to the limited accuracy of any measuring instrument.

If you were to measure the width of a book and write $w = 25.2$ cm, you are saying that:

The most likely width = 25.2 cm, but the possible error is 0.1 cm

i.e. largest possible width = 25.3 cm

smallest possible width = 25.1 cm

If you write $w = 25.20$ cm, you are now claiming to have made the measurement to 0.01 cm. i.e. a claim for much more accuracy than is justified by the measurement.

Students often run into trouble when they have to *combine* measurements. Here is a simple example. You measure the length, width and depth of a rectangular block and try to calculate the volume.

Results length l = 4.9 cm
width w = 2.9 cm
depth d = 2.1 cm
Volume $V = l \times w \times d$
$= 4.9 \times 2.9 \times 2.1 \text{ cm}^3$
$= 29.641 \text{ cm}^3$

Many students would leave the answer like this. *Would you*? Clearly not, since you are claiming a possible error of not more than 1 part in 29.461! A *sensible* claim would be $V = 30 \text{ cm}^3$, so your claim for accuracy is no greater than the accuracy of the separate readings.

A simple rule to remember: When quoting a final value, give it with no more significant figures than the *least* accurate of the readings you used to obtain the value.

You will be meeting some other ideas relating to measurment as you move through the course.

IMPORTANT QUANTITIES, UNITS AND DEFINITIONS

The table below contains a great deal of information. It is intended for reference as you go through the course, as a source of data and may be useful for check up while revising. It is *not* intended as a large block of facts to be learned early in the course. SI units are used throughout.

EXPRESSING NUMBERS

1. A decimal point may be shown as 1.9 or 1·9 or 1,9
2. Numbers are never started with a decimal point.
   0.19 is correct .19 is not
3. Numbers with a large number of digits should be arranged in groups of three, with a small space separating each group. e.g. 2 000 000 NOT 2,000,000
   34 567.890 1, not 34,567.890,1

PREFIXES

Prefix	Fraction	Symbol	Example
pico	10^{-12}	p	10^{-12} m = 1 pm
nano	10^{-9}	n	10^{-9} m = 1 nm
micro	10^{-6}	μ	10^{-6} m = 1 m
milli	10^{-3}	m	10^{-3} m = 1 mm
centi	10^{-2}	c	10^{-2} m = 1 cm
kilo	10^{3}	k	10^{3} m = 1 km
mega	10^{6}	M	10^{6} W = 1 MW
giga	10^{9}	G	10^{9} V = 1 GV
tera	10^{12}	T	10^{12} J = 1 TJ

IMPORTANT QUANTITIES, UNITS AND DEFINITIONS

Quantity and Symbol **Basic Quantities**	*SI and other permitted units* **units**	*Definitions and Notes*
Mass (m)	kilogram (kg) g = 10^{-3} kg tonne = 10^3 kg	All basic quantities are related to an accepted standard of that quantity. For example, the standard of mass is a piece of platinum-iridium kept at BIPM in Sevres.
Length (l)	metre (m) nm = 10^{-9}m μm = 10^{-6}m mm = 10^{-3}m km = 10^3m	As with all units, multiples and submultiples in factors of 10^{-3} m are preferred. The centimetre (cm) is a very convenient size and continues in use.
Time (t)	second(s) minute (min.) hour (h)	
Temperature (θ)	kelvin (K)	1°C is numerically equal to 1 K
Amount of substance (mol)	mole (mol)	1 mole is the *number* of particles equal to the number of atoms in 0.012 kg (12 g) of carbon 12. Numerically, this is the same as Avogadro's Number L ($L = 6.022 \times 10^{23}$) which is the number of molecules in a mole of substance.
Electric current (I)	ampere (A)	1 ampere is the current which, if flowing through two infinitely long electrical conductors placed 1 m in vacuum, would cause a force of 2×10^7 N per metre of each conductor.

Derived Quantities

Volume (*V*)	m^3 dm^3 (1 dm^3 = 1 litre) cm^3	
Density ($_\rho$)	kg^{-3} also kg^{-3} and g^{-3} cm	Density = mass per unit volume, $\rho = m/V$. For solids and liquids, ρ is often measured in g cm^{-3}.
Relative density (*d*)	no unit — a ratio	**Relative density is the ratio of the density of a substance to the density of a reference substance (usually water).**
Speed, *(u, v)*	m s^{-1}	Speed = distance moved per unit time.
Velocity* *(u, v)*	m s^{-1}	Velocity = distance moved per unit time in a given direction (or speed in a given direction).
Acceleration* *(a)*	m s^{-2}	Acceleration = velocity change per unit time $$a = \frac{v - u}{t} \text{ ms}^{-2}$$ When velocity is decreasing, *a* is negative.
Acceleration of **free** fall* *(g)*	m s^{-2}	*g* is the vertical acceleration of a body released on the earth's *surface if there are no opposing forces acting (eg. air friction).*
Force* *(F)*	newton (N)	Force is that which will change or tend to change the state of rest, uniform motion in a straight line or shape of a body. The unbalanced force causing acceleration can be calculated from $F = ma$ N. 1 newton (N) is the unbalanced force needed to give a mass of 1 kg an acceleration of 1 ms^{-2}.

Quantity and Symbol	SI and other permitted units	Definitions and Notes
Weight* (W)	newton (N)	On the earth's surface, the force acting on 1 kg is g N (approximately 10 N kg^{-1}), g is the gravitational field strength. For a mass m on the earth's surface, the weight is given by $W = mg$ N.
Pressure* (p)	N m^{-2} or pascal Pa	Pressure is the force per unit area acting perpendicular to a surface: $P = \frac{F}{A}$ Nm^{-2} for a column of liquid, $p = h \rho g$ Nm^{-2} where h is the vertical height of the column and ρ is the density of the liquid. Since p is proportional to h, it is common practice to measure p in m, cm or mm for liquid, eg. atmospheric pressure is usually quoted in mm of mercury.
Energy (E)	joule(J)	Not subject to simple definition. Exists in various forms, eg. *Potential* (chemical, gravitational and stored in elastic materials), *kinetic, heat, light* and other *electromagnetic waves, electrical* (potential and kinetic) and *nuclear.* Work done is the energy transferred. Work = force × distance moved in the direction of the force. Amount of energy stored = work done when the energy is released.
Power (P)	watt (W)	Power = work done per unit time: $P = W/t$, so work done = power × time. 1 W is a rate of working of 1 joule per second.
Frequency (f)	hertz (Hz)	Frequency is the number of complete vibrations each second: $f = 1/T$. 1 Hz is a frequency of 1 vibration per second.

Wavelength (λ)	metre (m) also μm, nm and cm	Wavelength is the distance between two consecutive in-phase points on a wave. For all waves, speed = frequency × wavelength $v = f\lambda$. For light and other electromagnetic waves, $c = f\lambda$. In vacuum, $c = 3 \times 10^8$ m s^{-1}
Heat capacity *(C)*	JK^{-1} or J $°C^{-1}$	Heat capacity of a body is the heat required to raise the temperature by 1 K (1 deg C).
Specific heat capacity *(c)*	J kgK^{-1} or J $kg°C^{-1}$	Specific heat capacity is the heat required to change the temperature of a unit mass of substance by 1 K (or 1 deg C). Heat capacity = $m\,c$ J K^{-1} Heat required to change the temperature of m kg of material by θ°C = $mc\theta$ J.
Latent heat *(L)*	J	Latent heat is the quantity of heat absorbed or released when there is a change of state without change in temperature.
Specific latent heat *(l)*	J kg^{-1}	Specific latent heat is the heat absorbed or released per unit mass when there is a change of state without a change in temperature.
Electric charge (Q)	coulomb (C)	Charge passed = current × time coulombs = ampere seconds $Q = It$

* These quantities are *vectors.* For full definition, any vector quantity must be defined in both *size* and *direction.* Other quantities need only be defined in size. They are called *scalar* quantities.

Quantity and Symbol	*SI and other permitted units*	*Definitions and Notes*
Potential difference (voltage) *(V)*	volt (V)	Potential difference between two points is the work done in moving 1 coulomb between the points. If the p.d. is V volts and the charge is $I\,t$ C, work done (usually released as heat) $= V\,I\,t$ J and power $= V\,I$ W. *Potential* is the p.d. between a body and earth.
Resistance (R)	ohm (Ω)	Resistance of a conductor $= \dfrac{\text{p.d. between ends of conductor}}{\text{current flowing}}$ $R = \dfrac{V}{I}\ \Omega$ For *metallic* conductors at constant temperature, V/I is a constant (**Ohm's Law**).
Refractive index (n)	ratio — no unit	Refractive index $n = \dfrac{\text{velocity of wave in first medium}}{\text{velocity of wave in second medium}}$ or $= \dfrac{\text{sin angle of incidence}}{\text{sin angle of refraction}}$ $= \dfrac{\sin i}{\sin r}$
Faraday constant (F)	coulombs/mole (C mol^{-1})	The Faraday constant is the number of coulombs of charge needed to liberate 1 mole of monovalent ion during electrolysis. $F = 96\,500$ C mol^{-1} approx.
Atomic number (Z)		Atomic number is the number of protons in an atomic nucleus.

Mass number *(A)*		Mass number is the total number of nucleons (protons + neutrons) contained in the nucleus of an atom. Atoms containing the same number of protons, but different numbers of neutrons, are called *isotopes* of the element.
Relative atomic mass of an element (A_r)	ratio — no unit	Relative atomic mass of an element is the ratio of average mass per atom in relation to 1/12 of the mass of a carbon 12 atom.
Relative molecular mass ratio (M_r)	ratio — no unit	Relative molecular mass is the ratio of average mass per molecule to 1/12 of the mass of a carbon 12 atom.
Half life $(t_{1/2})$	second (s)	Half-life of a radioactive substance is the time for half the atoms present to decay (disintegrate).