



The University of Sydney

**“The History of Physics”**  
**in the**  
**New Higher School Certificate Physics Syllabus**

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**Introduction**

The new HSC Physics Syllabus (1999) represents a significant change in the approach to teaching Physics (and Science generally). There is a greater emphasis on placing the content in a *social context*, and a greater emphasis on inviting students to consider the processes and outcomes of science. I believe that the new syllabus represents a sound response to the forces shaping the nature and needs of senior High School students at this time.

In many respects the content of the new syllabus is *incrementally* different from the previous syllabus, allowing teachers to draw on *existing* materials and pedagogies. However, in several important respects the new syllabus will require *radically new* content and new pedagogies if the intent of the syllabus authors is to be met. One area that almost certainly requires new content and new approaches to teaching concerns the “History of Physics” Prescribed Focus Area in the syllabus. My paper aims to provide some of the content for this Area, generally drawn from sources that might not be conveniently accessible to practicing teachers. I have not addressed pedagogical issues here, but there are exciting opportunities for adopting new approaches to teaching Physics in this area, such as

- Individual and group project work emphasising the skills needed to access primary and secondary resources from libraries and the Web,
- Participatory development of communication and collaborative skills through mini-talks (e.g. Faraday’s contribution to Electrosience), staged debates (e.g. Einstein and Bohr debate the meaning of quantum physics) and plays/performances (e.g. Act out a rocket experiment in Roswell or the effect of a V1 or V2 rocket falling on London; cf *The End of the Affair*).

- Exposing science students to some aspects of “postmodern” views of science in society, contrasting for example the *interpretational* character of History with the *positivist* character of Physics (see for example M Foucault, 1992, *The Archaeology of Knowledge*, Routledge ISBN 0-415-04537-1)

My approach to the task has been to extract from the Syllabus all of the elements that address the “History of Physics” Prescribed Focus Area and to provide one or two “readings” that exemplify significant aspects of the topic. In this way I hope to provide a lead into the topic, suggesting directions for further investigation. Owing to lack of time, I have not been able to cover all areas of the Syllabus. However, I have identified in the Tables *all* of the topics (so far as I can discern them) to help teachers ensure that their teaching programs cover all the elements of this Prescribed Focus Area.

### **The Shape and Thrust of the Syllabus**

It is useful to draw out from the Syllabus the essence of the “History of Physics” Prescribed Focus Area. You will recall that the Syllabus sets out the **objectives** of the program in the following terms

*Students will develop knowledge and understanding of*

1. *the history of physics*
2. *the nature and practice of physics*
3. *applications and uses of physics*
4. *the implications of physics for society and the environment*
5. *current issues, research and developments in physics*
6. *kinematics and dynamics*
7. *energy*
8. *waves*
9. *fields*
10. *matter.*

*Students will develop further skills in:*

11. *planning investigations*
12. *conducting investigations*
13. *communicating information and understanding*
14. *developing scientific thinking and problem-solving techniques*
15. *working out individually and in teams.*

*Students will develop positive values about and attitudes towards:*

16. *themselves, others, learning as a lifelong process, physics and the environment.*

Item 1 identifies the History of Physics as one of the objectives of the program. The Prescribed Focus Areas are **emphases** designed to increase students’ understanding of Physics. The History of Physics Prescribed Focus Area is described in this way:

*Knowledge of the historical background of physics is important to adequately understand natural phenomena and explain the applications of those phenomena in current technologies. Students should develop knowledge of:*

- *the developmental nature of our understanding of energy, matter and their interrelationships*
- *the part that an understanding of energy, matter and their interrelationships plays in shaping society*
- *how our understanding of energy, matter and their interrelationships is influenced by society.*

The three bullet points in the History Prescribed Focus Area represent (in my view) very difficult concepts that will be hard to teach well. They also represent an opportunity to excite students in ways that have not been emphasised in previous syllabuses. The **domains** of the Syllabus represent another dimension of the pedagogical framework. Students taking the Physics courses are expected to develop in each of the domains:

- *Knowledge and understanding*
- *Skills*
  - planning investigations
  - conducting investigations
  - communicating information and understanding
  - developing scientific thinking and problem-solving techniques
  - working individually and in teams
- *Values and attitudes*

The History of Physics Focus Area provides wonderful opportunities to entice students to enter into all of these domains.

The Physics Syllabus *specifies* quite narrowly the Historical items and activities to be included in the program. This does not preclude teachers and students from exploring other issues. However, it is my view that the entire Syllabus is very demanding and therefore there is little scope to find additional time to cover material beyond that which is examinable in the HSC examination. In any case, the items selected for detailed coverage in the Syllabus are, with a few exceptions, appropriate to give students insight into the History of Physics.

The remainder of this paper identifies what I believe are the “History of Physics” items in the Syllabus and presents selected readings and similar items. I have not attempted to unpack the **verbs** used to specify the individual items, although teachers should be aware that the actual verb used in each item is a very important indicator of (a) the depth to which the item may be examined in the HSC, and (b) the specification of the assessment bands for this aspect of the course.

The Stage 6 **Preliminary Course** has one “skills” module and four “content” modules:

- Physics Skills
- The World Communicates

- Electrical Energy in the Home
- Moving About
- The Cosmic Engine

History focus areas are specified in “Electrical energy” and “Cosmic engine.” There are no History focus areas in “Physics Skills,” “The World Communicates” or “Moving About.”

The Stage 6 **HSC Course** also has one “skills” module and four “content” modules:

- Physics Skills
- Space
- Motors and Generators
- From Ideas to Implementation
- Options:
  - Geophysics
  - Medical Physics
  - Astrophysics
  - From Quanta to Quarks
  - The Age of Silicon

History focus areas are specified for “Space” and “From Ideas to Implementation” as well as the options “Geophysics,” “Medical Physics” and “From Quarks to Quanta”. There is no History focus area in the other modules. I have been unable to identify the History items in the content specification for the “Medical Physics” option, although the Syllabus appears to indicate that it does exist!

In the remained of this paper I present the specific content for each History focus area, and provide some commentary and background readings.

Note that I have reproduced in some cases copyright materials in accordance with accepted practice. It is important that teachers who use these materials in the classroom do so in accordance with the applicable legal and moral considerations.

## Module: Electrical Energy in the Home

		<i>Students learn to:</i>	<i>Students:</i>
<b>1.</b>	<b>Society has become increasingly dependent on electricity over the last 200 years</b>	<ul style="list-style-type: none"> <li>• discuss how the main sources of domestic power have changed over time</li> <li>• assess some of the impacts of changes in, and increased access to, sources of power for a community;</li> </ul>	<ul style="list-style-type: none"> <li>• identify data sources, gather, process and analyse secondary information about one of the debates that took place to develop our current understanding about electricity from one of the following:               <ul style="list-style-type: none"> <li>* Volta and Galvani and their debate over animal and chemical electricity</li> <li>* Faraday</li> <li>* Ohm</li> </ul> </li> <li>• identify data sources, gather secondary information, process, analyse, present the information and use the available evidence to show how the type of energy sources and access to it has changed</li> </ul>

### Comments:

- 1) I have not provided readings for changes in domestic power sources. Christina Hardymen's *From Mangle to Microwave: the mechanization of household work*. (1988, Polity press, Cambridge ISBN 074560207X) covers aspects of the topic in an interesting way and would be a good source for project work. The US Library of Congress website titled *The History of Household Technology* has an extensive bibliography (<http://lcweb2.loc.gov/sctb/domestic.htm>) The story about the (commercial) battles between Edison and Westinghouse over the use of DC and AC power in distribution systems is also potentially very interesting for students.
- 2) There are many books and web resources on the topic of "electrification" in both economically advanced communities (in which case the story is historical, such as the history of the Snowy Mountains Scheme) or in developing communities (in which case the story is about contemporary socio-economic development).
- 3) Reading A regarding the Volta-Galvani debate is Chapter III from E. Whittaker, 1951, *A History of the Theories of the Aether and Electricity*, Thomas Nelson.
- 4) Regarding Faraday, I include as Reading B a paper written for the 1995 Science Foundation International Science School. The Wollaston-Faraday affair concerning the rotation of conductors in a magnetic field would be an excellent topic to explore as a scientific controversy. There is inter-personal tension and fallout regarding

Faraday's career. There is also the peculiar fact that Faraday's experiment was right for the wrong reason, and Wollaston's wrong for the right reason

- 5) I am unsure about "debates" surrounding Ohm. Ohm formulated an early version of the relationship we now call Ohm's law, by clarifying the nature of what we now call "voltage" and "current." It might be this work that is required by the Syllabus. Ohm was also involved in attempts to resolve questions about what we would now call "electrochemical effects" and "contact potentials" in electrolytic cells. I do not know whether the authors of the Syllabus had this matter in mind for this item – it is a very obscure topic, and Ohm was not the main protagonist. The included chapter (Reading A) from Whittaker covers both items and might give teachers a hint about the interpretation of this part of the Syllabus.

## Module: The Cosmic Engine

		<i>Students learn to:</i>	<i>Students:</i>
1.	<b>Ours is just one star in the galaxy and ours is just one galaxy in the universe</b>	<ul style="list-style-type: none"> <li>outline the historical development of models of the universe from Aristotle to Newton</li> </ul>	<ul style="list-style-type: none"> <li>identify data sources, gather, process and analyse information to assess one of the models of the universe developed from the time of Aristotle to Newton and identify the limitations placed on the development of the model by the technology of the time</li> </ul>
2.	<b>The first minutes of the universe released energy which changed to matter, forming stars and galaxies.</b>	<ul style="list-style-type: none"> <li>outline the discovery of the expansion of the universe by Hubble following its earlier prediction by Friedmann</li> </ul>	<ul style="list-style-type: none"> <li>process information to assess the relationship between a theory and the evidence supporting it using the work of Friedmann, predicting the expansion of the universe years before it was discovered.</li> </ul>

### Comments

- 1) Reading C is Chapter 2 *Origins of Modern Cosmology* from J. Silk, 1989, *The Big Bang*, W.H. Freeman, ISBN 0-7167-1812-X (paper)
- 2) There are many good books on the topic. Silk's book has an excellent reading list introducing the literature on the Big Bang – many of the books listed have a section on the History of the ideas about cosmology and the Big Bang.
- 3) A good book exploring this and other topics of relevance to the Syllabus is T. Kuhn, 1985, *The Copernican Revolution*, Harvard University Press, ISBN-0-647-17103-9 (paper). There is an excellent bibliography in this volume.
- 4) A book on this topic which I find profoundly interesting and which seems to be enjoyed by young and old is A. Koestler, 1959, *The Sleepwalkers*, Hutchinson.
- 5) It is my view that the authors of the Syllabus might have fallen for the trap of “inventing” history in the wording of the item about Friedmann and cosmic expansion. Reading D is *Chapter 10: Expansion* from E Harrison's wonderful book *Cosmology: The Science of the Universe* (1989, Cambridge University Press, ISBN 0-521-22981-2) gives a sense of the difficulties faced by a theory of discovery implied by the Syllabus statement. (Although I would urge teachers to help students make sure they can reproduce the expected story)

## Module: Space

		<i>Students learn to:</i>	<i>Students:</i>
1.	<b>Many factors have to be taken into account to achieve a successful rocket launch, maintain a stable orbit and return to Earth</b>	<ul style="list-style-type: none"> <li>describe Galileo's analysis of projectile motion</li> <li>discuss Newton's analysis of escape velocity</li> </ul>	<ul style="list-style-type: none"> <li>identify data sources, gather, analyse and present information on the contribution of Tsiolkovsky, Oberth, Goddard, Esnault-Pelterie, O'Neill or von Braun to the development of space exploration</li> </ul>
4.	<b>Current and emerging understanding about time and space has been dependent upon earlier models of the transmission of light</b>	<ul style="list-style-type: none"> <li>outline the features of the aether model for the transmission of light</li> <li>describe and evaluate the Michelson-Morley attempt to measure the relative velocity of the Earth through the aether</li> <li>discuss the role of critical experiments in science, such as Michelson-Morley's, in making determinations about competing theories</li> </ul>	<ul style="list-style-type: none"> <li>perform an investigation and gather first-hand or secondary data to model the Michelson-Morley experiment</li> <li>analyse and interpret some of Einstein's thought experiments involving mirrors and trains and discuss the relationship between thought and reality</li> <li>analyse information to discuss the relationship between theory and the evidence supporting it, using Einstein's predictions based on relativity that were made many years before evidence was available to support it</li> </ul>

### Comments:

- 1) The Galileo text, Reading E, is a translation of a section from Galileo's *Dialogues Concerning Two New Sciences*, taken from J. Newman, 1956, *The World of Mathematics*, Simon & Schuster.
- 2) I am not sure of the background to the Syllabus item "Newton's analysis of escape velocity" since I cannot find an example of Newton using this term. I hope that the reading I have included (Reading F) is what the authors of the Syllabus had in mind. It is from S. Sambursky, 1974, *Physical Thought from the PreSocratics to the Quantum Physicists: An Anthology*, Hutchinson & Co: London, ISBN-0-09-102850-7. The entire section is a translation from Newton's *Philosophiae naturalis principia*

*mathematica* (1687) , included to give a flavour of the mode of discourse used by this great scientist.

- 3) There is a very good web site on many aspects of space science, including the history of rocketry, known as *Spaceline*. Reading G, on Tsiolkovsky, is a sample of *Spaceline* copyright material, written by C. Lethbridge, taken from the *Spaceline* site at <http://www.spaceline.org/spaceline.html>
- 4) There are many accounts of aether theories in the literature. Most books on Special Relativity, including popular accounts and encyclopaedia entries, have information on the topic. It is common for these accounts to imply that aether theories were relatively new at the time of the Michelson-Morley experiment, but this is not so. Aether theories of various kinds can be traced to the Greek philosophers, and Newton expressed some of his views in terms of an aether theory, as shown in Reading H, from page 19 of E. Whittaker, 1951, *A History of the Theories of the Aether and Electricity*, Thomas Nelson.
- 5) Reading I on the Michelson-Morley experiment is from R. Resnick, 1968, *Introduction to Special Relativity* (John Wiley & Sons, ISBN 0-471-71725-8)
- 6) To *model* the Michelson-Morley experiment, it would be worth considering the analogy of rowing a boat across a stream, versus rowing up and down the river. It would be quite possible for students to discover that the time for the up-down journey is always longer than the across journey, for the same distance travelled.
- 7) Reading J, *IX The Relativity of Simultaneity*, is from a translation of Einstein's *Relativity : The special and the general theory, a popular exposition* (translated by Robert W. Lawson, London : Methuen, 1954 and many other editions) This volume is still widely available in public and school libraries. The clarity of Einstein's explanations is unparalleled. Reading K regarding Einstein's views on waves is quite technical, and taken from the wonderful biography *Subtle is the Lord* (A. Pais, 1982, Oxford University Press, ISBN 0-19-520438-7). I suspect that the "mirror" item mentioned in the Syllabus has been somewhat embellished as an aspect of the history of relativity.
- 8) I have included as Reading L an extract from the brilliant work of Pais' *Subtle is the Lord* to cover the topic of the role of the Michelson-Morley experiment in the development of Einstein's views. I hope this reading gives some insight into the complexity and difficulty of discovering and interpreting the history of the development of ideas!
- 9) Regarding the items referring to Einstein's predictions, the following considerations might be relevant:
  - Predictions of the Special Theory include time dilation, length contraction and the equivalence of matter and energy. So far as I know, none of these things was the subject of experimental research before the theory was developed.
    - Time dilation was confirmed in many ways following Einstein's prediction . The arrival on the ground of short-lived particles (mesons) produced high in the atmosphere by cosmic rays is often cited as an example. Students should be able to calculate the time dilation for comic ray products from data in texts.

- I am not aware of an experiment that demonstrates length contraction, although the interpretation of super-luminal motion in quasars relies in part on the effect.
  - Modern navigation systems (such as the Global Positioning System) *must* make relativistic corrections routinely. Students could calculate the rate of slowing of clocks in satellites or aircraft compared with terrestrial observers, and from this calculate the positional error in long journeys.
  - The equivalence of matter and energy is of course illustrated in atomic fission and fusion, as well as in the binding energy of atomic systems.
  - Although it is generally overlooked as the consequence of special relativistic effects, the *magnetic field* around a current-carrying conductor is in fact a strictly relativistic effect arising from the drift of electric charges in the conductor, as view by the external observer.
- Three well-known predictions of General Relativity are:
    - The anomalous precession of the perihelion of Mercury, which was known before Einstein's theory was developed, but unexplained.
    - The redshift of light in a gravitational field. It was claimed that this was confirmed by observations of the wavelength of spectral lines emitted by the Sun, but the experiment is rendered ambiguous because there are several other phenomena that lead to net line shifts in solar spectral lines. The shift of the spectral lines in compact companions (eg white dwarfs) of stars provide a more reliable test.
    - The deflection of starlight by the Sun, detected during a total eclipse. This was a difficult experiment and there is now some doubt about the reliability of the reduction of the data that were claimed to support the prediction..

10) There is a **lot of rubbish** on the web about relativity – it seems to be a topic that attracts web-literate cranks. In my experience, only about 10% of web sites discovered using search engines on the word “relativity” will return sound material.

## Module: From Ideas to Implementation

		<i>Students learn to:</i>	<i>Students:</i>
1.	<b>Increased understandings of cathode rays led to the development of television</b>	<ul style="list-style-type: none"> <li>outline Thomson's experiment to measure the charge/mass ratio of an electron</li> <li>discuss the impact of increased understandings of cathode rays and the development of the oscilloscope on experimental physics</li> </ul>	
2.	<b>The reconceptualisation of the model of light led to an understanding of the photoelectric effect and black body radiation</b>	<ul style="list-style-type: none"> <li>explain qualitatively Hertz's experiments in measuring the speed of radio waves and how they relate to light waves</li> <li>describe Hertz's observation of the effect of a radio wave on a receiver and the photoelectric effect he produced but failed to investigate</li> <li>identify Planck's hypothesis that radiation emitted and absorbed by the walls of a black body cavity is quantised</li> <li>identify Einstein's contribution to quanta and its relation to black body radiation</li> </ul>	<ul style="list-style-type: none"> <li>identify data sources, gather, process and analyse information and use available evidence to assess Einstein's contribution to quanta and their relation to black body radiation</li> <li>identify data sources, gather and process information to discuss Einstein and Planck's debate about whether science research is removed from social and political forces</li> </ul>
3.	<b>Limitations of past technologies and increased research into the structure of the atom resulted in the invention of the transistor</b>	<ul style="list-style-type: none"> <li>describe the de Broglie model of electrons in orbits around atoms</li> </ul>	<ul style="list-style-type: none"> <li>gather, process and present secondary information to discuss how shortcomings in available technology led to an increased knowledge of the properties of materials with particular reference to the transistor.</li> </ul>

		<i>Students learn to:</i>	<i>Students:</i>
<b>4.</b>	<b>Investigations into the electrical properties of particular metals at different temperatures led to the identification of superconductivity and the exploration of possible applications</b>	<ul style="list-style-type: none"> <li>outline the methods used by the Braggs to determine crystal structure and assess the impact of their contribution to an understanding of crystal structure</li> </ul>	

**Comments:**

- 1) Reading M, a description of Thomson’s experiment to measure  $e/m$ , is taken from F. Sears, M.. Zemansky and H Young, 1987, *University Physics* (7<sup>th</sup> ed., Addison-Wesley, ISBN 0-201-06694-7)
- 2) The American Institute of Physics history web site has good resources about the electron and cathode ray tubes (browse to <http://www.aip.org/history/electron/>) Old books on the topic of the CRO are often quite technical, and turn immediately to the details of the scanning circuitry. I am not sure of the emphasis that might be placed on this topic – interestingly, the capacity to make a useful oscilloscope depends on the use of electronic amplifiers which were in the early days based on vacuum tubes and thus on cathode rays. Cathode rays were important in *both* the tube itself and in the associated electronics.
- 3) Hertz’s experiments regarding what we now call radio-frequency electromagnetic radiation are discussed in Reading N, from E. Whittaker, 1951, *A History of the Theories of the Aether and Electricity*, Thomas Nelson. Note how Hertz used interference between a signal propagating in air and in a wire to determine the ratio of the speed in the two media (page 324 of the reading).
- 4) The story of Hertz and the photoelectric effect is contained in Reading O from E. Whittaker, 1951, *A History of the Theories of the Aether and Electricity*, Thomas Nelson.
- 5) Reading P, from Pais, *Einstein on Particles, Fields and Quantum Theory*, gives a useful summary of the linkages in early quantum mechanics. It is taken from an interesting Centennial Symposium to celebrate the work of Einstein, edited by H. Woolf, 1980, *Some Strangeness in the Proportion*, Addison-Wesley, ISBN 0-201-09924-1
- 6) Planck’s work on the thermodynamics of radiation is quite complex, and not usually studied in a first approach to the origins of quantum theory. Reading Q is from Whittaker’s *A History of the Theories of the Aether and Electricity*, and its technical inaccessibility is evident! There is a point in the development of the theory at which Planck assumed that the energy of the “vibrators” is constituted of equal discrete elements – these are the “quanta” that were so named later. Note that Planck was concerned with what we might call the “quantisation” of the sources of the fields.
- 7) Einstein’s contributions to the study of photoelectric emission are covered in Reading R from S. Sambursky, 1974, *Physical Thought from the PreSocratics to the Quantum*

*Physicists: An Anthology*, Hutchinson & Co: London, ISBN-0-09-102850-7. Note how Einstein explains that wave and corpuscular behaviour can co-exist, quite apart from the question of the “emission” of quanta.

- 8) I am unsure about the details of the Einstein-Planck debate mentioned in the Syllabus. The following quotation, from the American Institute of Physics website on Einstein (<http://www.aip.org/history/einstein/public1.htm>) might provide a hint to the topic. If this is the case, the book by Mark Walker, 1995, *Nazi science: Myth, truth, and the German atomic bomb*, New York: Plenum, ISBN 0-306-44941-2 appears to cover the material (I have not found a copy).

*The outbreak of the First World War brought Einstein's pacifist sympathies into public view. Ninety-three leading German intellectuals, including physicists such as Planck, signed a manifesto defending Germany's war conduct; Einstein and three others signed an antiwar counter-manifesto. He helped to form a nonpartisan coalition that fought for a just peace and for a supranational organization to prevent future wars. As a Swiss citizen Einstein could feel free to spend his time on theoretical physics, but he kept looking for ways to reconcile the opposing sides. "My pacifism is an instinctive feeling," he said, "a feeling that possesses me because the murder of men is disgusting. My attitude is not derived from any intellectual theory but is based on my deepest antipathy to every kind of cruelty and hatred.*

- 9) The background to De Broglie’s wave-theory of the electron is explained in his own words in the reading from R. Dugas, 1988, *A History of Mechanics*, Dover Publications, ISBN 0-486-65632-2
- 10) The Syllabus is presumably referring to the post-war development in Bell Labs of groups aiming to get better control of the electro-technologies of germanium and silicon materials. There are extensive, sound readings about this topic in on-line courses at Rensselaer Polytechnic Institute and at Stanford University  
<http://www.rpi.edu/~formam/it/transistor.html>,  
<http://rits.stanford.edu/siliconhistory/MisaT/DevelopTransistor/DevelopTransistor.html>
- 11) Reading T is a reprint of an article by William Bragg taken from J Newman, 1956, *The World of Mathematics*, Simon and Schuster. There is an instructive Java applet illustrating Bragg diffraction at  
<http://www.journey.sunysb.edu/ProjectJava/Bragg/home.html>

## Module: Option - Geophysics

		<i>Students learn to:</i>	<i>Students:</i>
1.	<b>Geophysics involves the measurement of physical properties of the Earth</b>		<ul style="list-style-type: none"> <li>identify data sources, gather and process information to discuss Huygen's and Newton's investigation of the shape of the Earth using pendulum measurements</li> </ul>
2.	<b>Some physical phenomena such as gravitation and radiation provide information about the Earth at a distance from it</b>		<ul style="list-style-type: none"> <li>process information to describe the significance of Jean Richers experiments with the pendulum in disproving the spherical Earth hypothesis</li> </ul>
3.	<b>Studies of past and present physical phenomena indicate that the Earth is dynamic</b>	<ul style="list-style-type: none"> <li>discuss the initial reluctance of the scientific community to accept the mobility of the Earth's plates</li> </ul>	

### Comments

- 1) The following lead-in to the work of Huygens and Newton in this context is from the on-line Encycopaedia Britannica, at <http://www.britannica.com/bcom/eb/article/4/0.5716,108974+4+106190.00.html>

*The period from Eratosthenes to Picard can be called the spherical era of geodesy. A new ellipsoidal era was begun by Newton and the Dutch mathematician and scientist Christiaan Huygens. In Ptolemaic astronomy it had seemed natural to assume that the Earth was an exact sphere with a centre that, in turn, all too easily became regarded as the centre of the entire universe. However, with growing conviction that the Copernican system is true--the Earth moves around the Sun and rotates about its own axis--and with the advance in mechanical knowledge due chiefly to Newton and Huygens, it seemed natural to conceive of the Earth as an oblate spheroid. In one of the many brilliant analyses in his Principia, published in 1687, Newton deduced the Earth's shape theoretically and found that the equatorial semi-axis would be 1/230 longer than the polar semi-axis (true value about 1/300).*

*Experimental evidence supporting this idea emerged in 1672 as the result of a French expedition to Guiana. The members of the expedition found that a pendulum clock that kept accurate time in Paris lost 2 1/2 minutes a day at Cayenne near the Equator. At that time no one knew how to interpret the observation, but Newton's theory that gravity must be stronger at the poles*

*(because of closer proximity to the Earth's centre) than at the Equator was a logical explanation.*

- 2) There is a timing inconsistency in the extract above, since the date of publication of the Principia is 1687 while the loss of time in the pendulum clock was reported in 1672. I understand that the person who told Newton about this was the Jean Richter mentioned in the Syllabus, but I have not had time to research the connection.
- 3) There is a superb web site covering tectonics and other aspects of geology at <http://www.ucmp.berkeley.edu/geology/tectonics.html>. You can check out an animation at <http://www.ucmp.berkeley.edu/geology/anim3.html>. And the history at <http://www.ucmp.berkeley.edu/geology/techist.html>. There are many references to the literature at these sites.

**Module: Option – From Quanta to Quarks**

$$\frac{1}{\lambda} = R \left( \frac{1}{n_f^2} - \frac{1}{n_i^2} \right)$$

$$\frac{1}{\lambda} = R \left( \frac{1}{n_f^2} - \frac{1}{n_i^2} \right)$$

		<i>Students learn to:</i>	<i>Students:</i>
1.	<p><b>Problems with the Rutherford model of the atom led to the search for a model that would better explain the observed phenomena</b></p>	<ul style="list-style-type: none"> <li>• discuss the structure of the Rutherford model of the atom, the existence of the nucleus and electron orbits</li> <li>• analyse the significance of the hydrogen spectrum in the development of Bohr’s model of the atom</li> <li>• discuss Planck’s contribution to the concept of quantised energy</li> <li>• define Bohr’s postulates</li> <li>• Describe how Bohr’s postulates led to the development of a mathematical model to account for the existence of the hydrogen spectrum:</li> <li>• discuss the limitations of the Bohr model of the hydrogen atom</li> </ul>	<ul style="list-style-type: none"> <li>• process and present diagrammatic information to illustrate Bohr’s findings with the Balmer series</li> <li>• solve problems and analyse information using</li> <li>• identify data sources, gather, process and analyse secondary information to identify the difficulties with the Rutherford-Bohr model, including its inability to completely explain               <ul style="list-style-type: none"> <li>– the spectra of larger atoms</li> <li>– the relative intensity of spectral lines</li> <li>– the existence of hyperfine spectral lines</li> <li>– the Zeeman effect</li> </ul> </li> </ul>

2.	<b>The limitations of classical physics gave birth to quantum physics</b>	<ul style="list-style-type: none"> <li>describe the impact of De Broglie's proposal that any kind of particle has both wave and particle properties</li> <li>describe the confirmation of De Broglie's proposal by Davisson and Germer</li> <li>explain the stability of the electron orbits in the Bohr atom using De Broglie's hypothesis</li> </ul>	<ul style="list-style-type: none"> <li>gather, process, analyse and present information and use available evidence to assess the contributions made by Heisenberg and Pauli to the development of atomic theory</li> </ul>
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		<i>Students learn to:</i>	<i>Students:</i>
3.	<b>The work of Chadwick and Fermi in producing artificial transmutations led to practical applications of radiation</b>	<ul style="list-style-type: none"> <li>identify the importance of conservation laws to Chadwick's discovery of the neutron</li> <li>describe Fermi's first experimental observation of nuclear fission and his demonstration of a nuclear chain reaction</li> <li>identify that Pauli's suggestion of the existence of neutrino is related to the need to account for the energy distribution of electrons emitted in <math>\beta</math>-decay</li> </ul>	<ul style="list-style-type: none"> <li>gather and analyse data to assess the impact of Pauli's suggestion of the neutrino on Fermi's work</li> <li>analyse information and use available evidence to assess how Chadwick's and Fermi's work changed understanding of the atom</li> </ul>

### Comments

1. This module is orientated towards the "History of Physics" in much of its presentation. It is in fact quite common for the entire subject to be taught in this way, through to senior years at University. As a result, there is a lot of material available on the topic. I have for example explored the material available in the *Encyclopaedia Britannica* CD pack, and found it to be quite well written, comprehensive and (so far as I know) accurate.
2. I have included an extensive reading (Reading U) of the history of particle physics from the excellent introductory book by F. Close, 1983, *The Cosmic Onion*, Heinemann Educational, ISBN 0-435-69171-6.
3. The role of serendipity in science is described in an excellent book by R. Roberts, 1989, *Serendipity: Accidental Discoveries in Science*, John Wiley and Sons, ISBN 0-471-50658-3. Reading V describes several accidental discoveries in this area of physics.

4. Reading W includes parts from Bohr (*On the constitution of atoms and molecules*) and De Broglie (*The wave nature of the electron.*) It is taken from S. Sambursky, 1974, *Physical Thought from the PreSocratics to the Quantum Physicists: An Anthology*, Hutchinson & Co: London, ISBN-0-09-102850-7.