Teaching ideas for Option B: Engineering physics

As a new option topic, this may be a popular one for students to study. Although some might argue that this topic contains a considerable amount of physics that other syllabuses have long ago dropped from their content, the topic is very well suited to students who would like to go on to study mechanical engineering of any kind at university. Incorporating material on thermodynamics and thermodynamic cycles, which had previously been part of the additional HL (AHL) material for the old topic on heat and thermodynamics, has relieved the syllabus for HL students, while keeping this interesting aspect of physics there for those who would like to study it. The AHL material in this unit concentrates on the physics of fluids and on forced oscillations and resonance, material that has been removed from the old topic on waves.

Some useful points to consider are:

- This topic looks at three ideas in physics, all of which are essentially mechanical in nature: rotational dynamics of solid objects, thermodynamics of gases and dynamical aspects of fluids, thereby giving a well organised and sensible overview of the physics involved with matter in the three basic states.
- In Subtopic **B.1**: Rigid bodies and rotational dynamics, only ‘basic geometrical shapes’ are to be considered. This suggests shapes such as spheres, cylinders, regular tetrahedra and perhaps cones or regular prisms. The key idea here is that instead of considering an object as a point particle (which is what students have done until now) it is necessary to consider it as a collection of many points, all of which can be moving and rotating with different motions and velocities.
- Those students who are following the HL Mathematics may find that the mathematical content in this part of the topic is slightly easier to deal with than those following other maths courses.

Ideas for teaching the topic

- It may be a good idea to begin the teaching of this topic by revising ideas about turning moments and what is required to make an object rotate. Then students can examine how it is possible to apply Newton’s laws of motion (covered in Topic **2**: Mechanics) to objects that are rotating. There are good symmetry arguments here.
- Much of section **B.1** can be dealt with in this way. Look at what Newton’s laws have to say about linear motion and see if this predicts what must happen for objects that are rotating. So, for example, momentum becomes angular momentum and acceleration becomes angular acceleration. This links directly with aim 10 of the group 4 aims in the IB Physics guide.
- Deriving classically the moments of inertia for a number of regular shapes should help students to accept that there is a method used by physicists that can be applied to any example, it is only the complication of the mathematics that makes one result more difficult to obtain than another, although students are not going to be required to be able to do this. Moments of inertia will be provided in questions that require calculations.
- It will be good to make sure students are familiar with and can use graphs of angular displacement against time, angular velocity against time and torque against time.
- Section **B.2** can be taught using a pV diagram for an ideal gas. Thermodynamic processes such as: isothermal, isochoric, isobaric and adiabatic processes can be shown on the pV diagram to good effect. This will lead to the first law as a kind of conservation of energy principle, and from this the idea of a thermodynamic cycle.
- The concept of entropy and its importance in the second law can be taught by considering how many different ways there are to arrange objects. The well-used idea that $S = k\log(W)$ will be familiar to some, although this is not formally required. It is required that students understand that changes in entropy are associated with changes in thermal energy at a given absolute

temperature: $\Delta S = \Delta Q/T$. Both the Clausius and the Kelvin interpretations of the second law should be examined. This will link nicely with aim 5 of the group 4 aims in the IB Physics guide.

- The AHL material in this topic concentrates on fluid dynamics and on forced vibrations and resonance. It is an area of physics that promotes a lot of experimental and investigative ideas for extended essays. Although there are no required investigations for this topic, it is also a topic that lends itself well to practical activity.

Practical activities

- A model steam engine can provide a useful demonstration of a thermodynamic cycle at work. These can be purchased for a relatively small amount and are much loved by students. If teachers have contact with a local garage or car specialist, it may be a good idea to get someone who knows engines very well to talk students through what is happening in a car engine, so that they can see that this is also a thermodynamic cycle in operation.
- Students might like to observe a variety of cars and look for what physical features of the car are important in considering how well the car moves through the air. Most modern cars have roughly the same shape; students should realise that there must be a reason for this: physics!
- A fun competition with students is to ask them to produce something made out of a sheet of paper that will stay in the air for the longest time when launched. Although most students will make a paper plane, some might be more adventurous and make a simpler shape like a cylinder. Results can be very surprising if you can find a way of launching them from high above the ground! It will be a good discussion to get students to consider what aspects of their shapes aid them to remain in the air? This leads to the idea of a Reynolds number.
- A clear Perspex tube filled with liquid (this could be water or a more viscous liquid such as glycerol) will allow students to investigate a number of interesting ideas about the time it takes for an object (a small steel ball is good and a ball of similar size but lower density may be even better) to fall a certain distance through the liquid. Students can film this on their mobile phones and play it back using SloPro or similar app to detect when the ball is falling at terminal velocity.
- If you are fortunate enough to have access to a wind tunnel, then a range of investigative work can be undertaken: for example, measuring the lift force for a range of attack angles of a basic wing shape will provide useful context for the understanding of the Bernoulli effect.
- For those without the luxury of a wind tunnel, students can mimic the flight of a swinging cricket ball by projecting balls that have one side very smooth and one side rough. (Although physicists have long debated why cricket balls sometimes swing and sometimes do not swing, the Bernoulli effect has to play some part in it.)
- Students should try to investigate resonance in a number of different situations where possible. One way of doing this is to use a mass on a spring (use two normal springs in series so that spring constant is fairly small) and have the oscillations of this driven by a vibrator that is connected to a signal generator. Students can then investigate how the amplitude of the oscillation varies with the forcing frequency, producing the typical resonance curve.
- A large-scale model of Barton's pendulums is also good for students to see the effect of a driving frequency, and this is easy to make for yourself if you do not already have one.
- An easy example of how an oscillation can be damped can be performed using a small mass suspended by two sets of two strings in a V shape. Pieces of card of varying area can then be inserted into the gap between the strings (and held there, where necessary, with some tape or adhesive putty) to damp the oscillatory motion. A number of different investigations can come from this simple idea, such as: how the area of the card affects the amplitude of the oscillations; how the area of the card affects how many oscillations the mass makes; or how the area of the card affects how many oscillations the mass makes before its amplitude has

been reduced by a certain amount. This will link nicely with aim 6 of the group 4 aims in the IB Physics guide.

- There are some modelling software packages available that can do this, too. These will link closely with aim 7 of the group 4 aims.
- Please see the available practical notes for further ideas.

ICT

- Video cameras on mobile phones can be used to good effect when students investigate objects such as a ball falling through a liquid. The slow motion play-back facility available as an app can enable students to make good quality measurements of the fall.
- Fluid dynamics is an area of physics that lends itself particularly well to computer modelling. The US company Craft Tech Inc. have developed a very good set of software to model various fluid dynamics situations, from the effect of jet planes on the ground to the unstable flow of fluids due to cavitation. Examples can be seen on: http://spinoff.nasa.gov/Spinoff2010/ct_2.html
- A data logger with a position sensor can be used to good effect in investigations about oscillations.

Common problems

- Students can find the first law of thermodynamics confusing if they are not sure about the sign convention of work done. This law is an interesting one to teach because of the way teachers learnt it in the first place. To illustrate this, consider the first law as: $\Delta U = \Delta Q + \Delta W$; ΔU, the change in internal energy, is positive if the internal energy increases, i.e. the gas becomes hotter. This will happen if the sum of ΔQ, the thermal energy exchanged, and ΔW, the work done, is also positive. So this requires ΔQ to be positive if the thermal energy is absorbed and ΔW to be positive if work has been done on the gas. Conversely, when ΔQ is negative this means that thermal energy has been lost from the gas to the surroundings, and when ΔW is negative work has been done by the gas on the surroundings.
- Another way to deal with the first law is by writing: $\Delta U = \Delta Q - \Delta W$. In this case it is important to realise that ΔW must be positive if work is done by the gas on the surroundings.
- Physics textbooks may quote this law in either of the above ways, and it is vital that students understand the convention being applied in each case.

Theory of knowledge (TOK)

- As we have seen here and in previous topics, physics uses models of many different kinds to help explain the behaviour of physical systems. Because of our growing understanding of physics and our better observations of physical systems, these models are often modified or replaced with better ones. Much of the physics in this topic has not required a change of model for a long time, perhaps suggesting how good the model is. Are there examples of models in other areas of knowledge that have not changed for a long time? If so, what are the reasons for these models remaining unchanged for so long?
- People pass on their knowledge to others using language. What role does folklore and past experiences recalled in anecdotal stories play in this? How much have historical stories and myths hindered or helped the growth of knowledge in various cultures of the world? The excellent book by Arthur Koestler called *The Sleepwalkers* provides numerous examples.

International-mindedness

- The physics involved in the engineering principles of this topic is universally understood and does not require any input from specific cultural learning. Although it may be that different countries have different safety standards (as used by engineers in their designs), the physics on which these standards is based is still essentially the same. During the period of time that scientists were learning about this, there was considerable debate over the application of ideas from scientists in various different countries. It is only by collective thinking and agreement that ideas and their applications can become universally accepted.

- The ownership of various natural resources can be a difficult political problem for governments to settle. When scientists share common knowledge of the physics involved, international decision making is made easier. This has led to several international projects, especially where locations of resources cross national boundaries.