ACTIVITY BRIEF

Physics of performance effects

The science at work

The quality of a performance can be greatly enhanced by careful use of sound and lighting. It doesn't matter whether the performance is being given in a theatre, a school sports hall or a garage - knowledge of the physics of sound and light helps improve the listening and watching quality enormously. Sound, lighting and vision engineers have key roles in ensuring performances sound and look their best.

Your brief

For the unit *Physics of performance effects* you need to:

produce a portfolio of evidence which considers how light and sound can be used in a performance and the science behind the design of a lighting and sound system in a performance you attended.

This needs to include:

A. a design for a sound system and appropriate control system for a venue you have chosen including:

- *details of the venue you have chosen*
- *the use of the correct scientific terminology to explain the characteristics of sound*
- *the results obtained from conducting relevant experiments in relation to the speed of sound, reflection, refraction, diffraction, resonance, interference, superposition and absorption of sound to show how sound behaves in your chosen venue;*
- *details of the type/arrangement of microphones and loudspeakers to be used and the function of each component part of the system;*
- *details of how the shape of a performance area, position of the performers/audience and materials, as part of the set, used in the performance affect the quality of the sound in the venue*
- *details of how the control system is used.*

B. a design for a lighting set-up and control system for a performance, or part of a performance, of your choice including:

- *the use of correct scientific terminology to explain the characteristics of light*
- *details of experiments you have conducted into reflection, refraction and colour*
- *how a variety of lighting effects could be incorporated into the lighting set-up*
- *how the control system is used.*

C. a description and evaluation of a sound and lighting system used in a performance you have attended including:

- *specific details of the lighting and sound systems used. You should use correct scientific terminology and scientific principles in your description and evaluation*
- *specific details of how lighting and sound effects are used in the performance and the scientific principles behind these effects; this will include the use of correct scientific terminology*
- *a calculation of the total cost of the lighting for the complete performance.*

Task 1 Sounds Good

You will have access to *The MODEL project: Practical physics at work* (Institute of Physics). The DVD ROM contains a video sequence called *Sounds Good* which has four sections. Use *Study sheet: Sounds good* in conjunction with the DVD ROM to produce notes demonstrating you can use the correct terms to describe sound.

Make use of your knowledge to describe different types of microphone. *Practical sheet: Using a swept sine wave to investigate the acoustic behaviour of a room* will guide you.

Task 2 Sound and Light

You will have access to the *Engineering Everywhere* DVD ROM. One of the sections is called *Engineering television* and contains a video filmed as the daytime TV programme *This Morning* went out live.

After watching the video make further notes on the type and uses of microphones. Use *Study sheet: Colour filters* to provide the evidence that you can use the correct terminology and understand the physics of colours and filters. In addition, do some calculations involving theatrical lamps. You will need *Information sheet: Luminator*.

When you have completed tasks 1 and 2 you are ready to carry out your investigation. Use *Study sheet: Venue check list* to collect the details of your chosen venue that are required for your portfolio.

STUDY SHEET

Sounds good

The video *Sounds Good* (found on the Institute of Physics DVD ROM: *The MODEL project: Practical physics at work*) has four sections which may be watched separately. Your teacher will let you borrow a copy. Before watching a section, read the introduction to it (given below) and make any notes or observations that you are asked to make. After viewing the section, try to answer the questions given.

Section 1

Acoustic engineering

The Milton Keynes Theatre opened on 4 October 1999. The theatre was built with the most technically advanced equipment available at the time. It can accommodate a vast range of productions, from large-scale West End musicals, to smaller, more intimate drama. The auditorium ceiling has been carefully designed to accommodate various shows and can be lowered or raised depending on the scale of the production. The seating can also be moved around within the auditorium to vary the capacity from between 900 and 1,400 people.

This section has interviews with John Young, the Director of Milton Keynes Theatre and with Trevor Cox, the Professor of Acoustic Engineering at Salford University.

During the interview with John Young, try to observe as much as you can about the theatre, its construction and the special facilities that enable it to adapt to different performances.

1 If you are designing a theatre or concert hall, what are the basic requirements for it to fulfil its purpose? For example it must have seats! (Although some venues can even dispense with these!).

2 How could these basic components affect the sound quality in the venue?

3 What types of materials can you see that have been used in the fitting out of the Milton Keynes Theatre? How might these affect the sound quality

4 Trevor Cox says that he is sitting in a room that is "*designed to make music sound particularly nice*".

   What features of his room can you identify that might play a part in this design?

5 John Young says "*A lot of older play houses and opera houses have stunning acoustics, so obviously they knew what they were doing!*"

   The *Roman Theatre of Orange*, in the town of Orange in southern France, is one of only three Roman theatres left standing in the world. It is still used to stage plays and operas. It can seat up to 10 000 people.

   On its website, the *Picture Gallery* gives some excellent views of the theatre (http://www.theatre-antique.com/en/orange/298-discovery/). You can also look at the French site http://www.theatre-antique.com/fr/orange/ if you want to practice your French! These web pages refer to its wonderful acoustics.

   What features of the Roman Theatre contribute to its 'wonderful acoustics'?

Section 2

Studying sound

The acoustic behaviour of any room or space depends both on its shape and the design of the materials and furnishings within it. In this section Trevor Cox describes some of the materials that are used to modify the acoustic properties of a room and how they do this.

1 What is an anechoic chamber?

2 How does the construction of the anechoic chamber, shown in this section, help it to perform in the desired way?

3 Use is made of *diffusion* and *absorption* of sound to modify the acoustic properties of the space.

What materials are used for these different jobs? Can you recognise how these are used in the Milton Keynes Theatre?

4 Trevor Cox demonstrates how a '*swept sine wave*' is used to investigate the reverberation times in a room.

What is a '*swept sine wave*'?

You may be asked to use the *Practical Sheet: Using a swept sine wave to investigate the acoustic behaviour of a room*. This tells you how to generate a swept sine wave to use in your investigations.

Section 3

Controlling Sound

In a modern theatre it is important to be able to change the sound characteristics of the auditorium, so that it can be used effectively for a wide range of different events. The theatre need to be able to attract all these different events if it is going to be profitable! In this section, Trevor Cox explains how they control sound in his university department and John Young describes how they change the acoustic properties in the Milton Keynes theatre.

1 What changes are made to the Milton Keynes theatre when it is changed from concert mode to drama mode?

2 How do these changes alter the behaviour of the theatre to suit the two modes?

3 What is reverberation and what is reverberation time?

You might want to check the references given here, for more information:

- http://hyperphysics.phy-astr.gsu.edu/Hbase/acoustic/reverb.html
- http://www.harmony-central.com/Effects/Articles/Reverb/.

Section 4

Using sound

In this section, both Trevor Cox and John Young talk about ways in which you can improve the acoustic properties of your bedroom. Not surprisingly they mention similar things.

List the different actions they suggest, with a brief explanation of how they will affect the sound.

PRACTICAL SHEET

Using a swept sine wave to investigate the acoustic behaviour of a room

In this practical you will be using a microphone. It is important that you understand something about microphone types and characteristics. See what you can find in an Internet search. A list of possible sites to explore is given at the end of this sheet.

A swept sine wave is one that changes its frequency in a smooth fashion over a pre-determined range in a particular time. In section 2 of the *Sounds Good* video, Professor Trevor Cox uses a swept sine wave that lasts for about 3 seconds, starting at a frequency below the normal minimum for audible sounds, and rising to a frequency above the normal maximum. If you want to check the maximum limit for your hearing, you might use the tones supplied on the following site, which supplies mobile phone tones that your teachers might not hear! But beware, computer speakers may themselves not reproduce frequencies this high.

http://www.ultrasonic-ringtones.com/

You will need to use a tone generator, such as the NCH tone generator, to create a tone that has the properties you have set from the criteria given above. You can observe the wave form of the tone and, if necessary, adapt it by playing it through sound analysis software such as *Audacity*.

Attach a speaker to your computer and position it towards one side of your room. Connect a microphone to the computer and check that your sound software (e.g. *Audacity*) can pick up sounds relayed from the microphone. You will need to test that you can record and display sounds played into your microphone.

- Do you know what type of microphone you are using?
- Can you describe it using some of the terms you have learnt about microphones?

When you are happy that the system is operating correctly, place the microphone near the centre of your room. Use the software to record the swept sine wave when it is played through the speaker.

- What can your recording tell you about the acoustic properties of your room?

If possible try to change the acoustic properties of the room by pulling the curtains or lowering blinds, or adding more people to the room.

- Do these changes show in the recording you now make?

Useful references

http://www.soundonsound.com/sos/1995_articles/jun95/microphones.html Brief guide to microphone types.

http://www.dummies.com/WileyCDA/DummiesArticle/id-2509.html Simple introduction to how different microphone types work.

http://www.audio-technica.com/cms/site/cb226162b8ac177e/index.html Comprehensive introduction to microphones, polar patterns etc.

STUDY SHEET

Sound and light *This Morning*

Start by watching the video sequence *Engineering television* on the *Engineering everywhere* DVD ROM (your teacher will let you borrow a copy). The video takes you behind the scenes of the daytime TV show *This Morning* as it goes out live.

Sound

In the video, Chris Hossent (one of the vision engineers on *This Morning*) shows you various aspects of the work done to get the programme broadcast. Chris introduces sound engineer Nicky Allen. Nicky explains her responsibilities on the show and talks about some of the equipment she uses.

1 Nicky talks about both omni-directional and directional (or unidirectional) microphones.

What is the difference between these two types?

2 Nicky also shows us an SM58. This is refers to the Shure SM58 microphone. The *User Guide* for this microphone can be viewed here: http://www.shure.com/stellent/groups/public/@gms_gmi_web_ug/documents/web_resource/us_pro_sm58_ug.pdf

Explain which features described in the *User Guide* demonstrate that the microphone is unidirectional.

3 Look at the frequency response characteristics given in the *User Guide*. Explain whether these match the normal frequency limits for human hearing.

What else do the frequency characteristics tell you about the microphone's performance?

Lighting

Chris also introduces lighting director Mark Ewings, who describes some of his responsibilities with the show and some of the equipment they use.

1 Mark demonstrates to you how the light from a lamp can be adjusted. The lamp he is using is an *ARRI Daylight Compact 1200*. You can access technical information about this lamp here: http://www.arri.com/prod/lighting/03_description.php?swid=L1.73725.B

The Photometric Data is of the most interest to you. It gives details of the beam diameter in the 'spot' and 'flood' positions described by Mark.

Where must the lamp be placed with reference to the principal focus of the lamp lens, for the beam to spread as in the 'flood' position? How is this different for the 'spot' position? Draw two sketches to illustrate how the lamp is positioned when it is in the 'flood' and 'spot' positions. Mark on your sketch where the principal focus of the lens would be in each case.

The photometric data gives you information on the beam diameter and light intensity at different distances for different lamp positions. Use this data to demonstrate that the intensity of light is inversely proportional to the distance from the light source squared:

Intensity $\alpha = 1/(\text{distance from source})^2$

2 Earlier in the sequence, a technician is seen fitting a filter sheet to a lamp. You may have used filters in colour mixing experiments, but stage lighting designers can select from a huge range of colours. *Data sheet: Colour filters* asks you about the spectral charts for a number of different filters. You might want to look at the wide range available from a supplier such as Lee Filters: http://www.leefilters.com/lighting/

3 The *Information sheet: Luminator* gives technical details for one type of theatre lamp, a LUMINATOR follow spot. You may wish to find out what a 'follow spot' is used for on the stage before carrying on with this task.

   a Look at the data sheet for the follow spot. Using the spot rating of 410 W, what current would the lamp draw at the rated voltage (120 V)?

   b Why would it not be possible to run this lamp from a UK mains supply without some adaptation? Explain what you would need to provide if you wanted to run this spot from a UK mains supply.

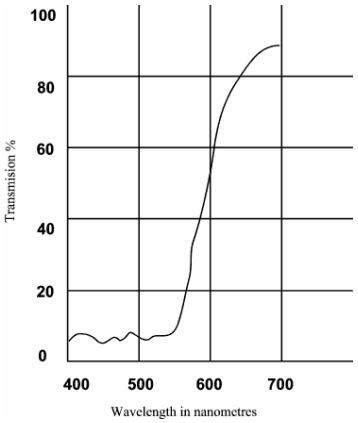
   c If the follow spot was used at full power for the whole of a 90 minute performance, at what cost would this be? You will need to find out first what the cost is per unit of electricity in your area.

STUDY SHEET

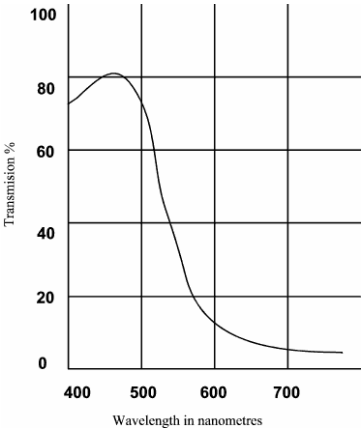
Colour filters

Each of these filters is designed to allow a particular colour to pass through it. Identify which colour each filter is designed for, giving the reasons for your choice.

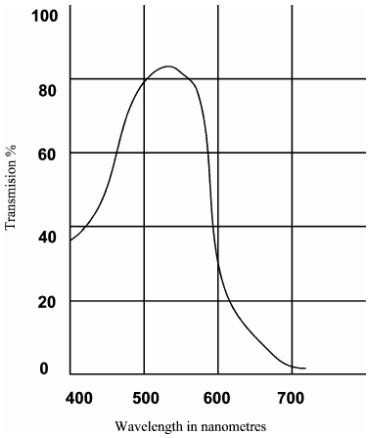
A



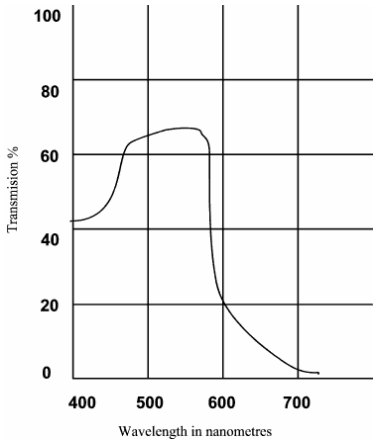
B



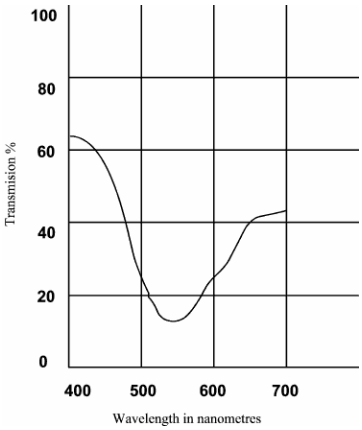
C



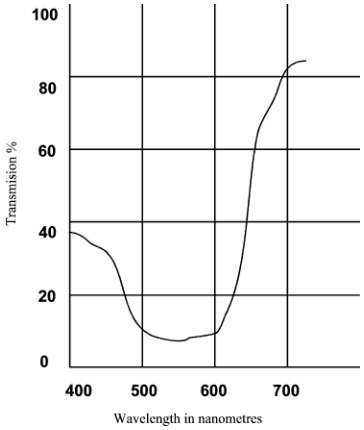
D



E



F



INFORMATION SHEET

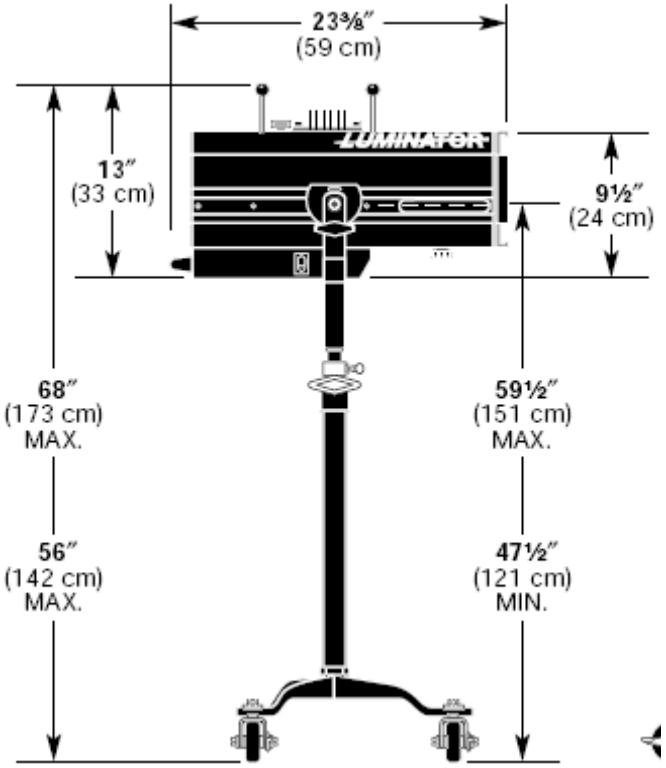
Luminator

The Luminator is a 360 watt short- to medium-throw follow spot. It gives a narrow, hard- or soft-edged beam which zooms from 1.3 degrees to 9.3 degrees. The light sources are high performance FLE, ENX and FXL quartz halogen lamps.

The Luminator can be used at any time and place where manual control of a lighting beam is required to follow a performer and to vary beam size, quality and colour. It has a top-mounted iris, colour boom and dimmer control handles, making it easy to use.

Specifications:

- housing: extruded and die cast aluminium construction
- rating: 120 V AC 4.0 A max
- lamp: 410 watts max 82 volt MR-16 type
- weight: 12.6 kg for lamphouse only



The link given below will take you to the data sheet for the LUMINATOR follow spot if you want to read more about it. You will have to download the sheet as an Adobe Acrobat document.

http://mail.altmanltg.com/publicsynergy/docs/BDDocument.asp?Action=View&ID={8885AE8E-EF8A-47C9-92E1-AEDD99587001}&ReturnTo=BDSearch%2Easp

STUDY SHEET

Venue check list

The lighting and sound system you design must match the venue that you choose to use. Each venue will have its own characteristic acoustical properties. Its size, shape and location also influence the practicalities of erecting light and sound equipment. And then there is the question of the availability of this equipment.

This check list will provide you with the basic information you require to start to plan your system.

The shape of the performance area

The performance area need not be a fixed stage. You may be able to use any suitable space in your venue, if it is a sports hall for example. In this case, you will need to identify which parts of the venue could be used for performance.

Where possible draw scale plans showing these measurements.

- What are the dimensions of the performance area?
  - width
  - depth
  - height

  Use these to estimate the volume of the performance area.
- If there is a stage:
  - where are the exits and entrances to the stage area?

    Mark these on your plan.
  - is it raked (sloping down from back to front to give the audience a better view) and if so, what is the slope?
  - does it have wings and if so, what size and height are these?
- If there is mobile or portable staging:
  - what size and shape are the stage modules?
  - what heights can be produced?
  - what area can be covered with staging?

The position of the audience

Obtain or draw a seating plan. Most theatres and commercial venues will have one for booking seats at performances. Examples are given on the references sheet.

- What are the dimensions of the audience area?
  - width
  - length
  - height of ceiling

- What is the position and nature of:
  - seating - Fixed or moveable: if moveable, what arrangements can be constructed?
    - Is the seating tiered or can it be tiered using staging blocks?
  - the materials for the seating?
  - the materials covering the walls and ceiling of the audience area?

    What acoustic properties are these likely to have?
  - entrances and exits?
  - disabled access – or provision for wheelchairs?

The position of the performers

If your venue has a fixed stage, you can note the details outlined below. If there is no fixed stage, you should consider how the performers will be able to move around the back stage equipment and make entrances and exits smoothly.

- How much of the stage area is useable by performers?
- Can the stage area be changed, e.g. using a 'thrust stage'?
- Can the shape be adapted to perform 'theatre in the round'?
- How does the stage construction (back wall, wings, proscenium arch etc.) affect sound projection from the stage?
- Are some areas better than others?

The materials used in the performance area

If there is a fixed stage, you can note what materials are used in its construction. However, as with a portable stage, you can also note what materials can be imported onto the stage, or to make the back wall and wings of a portable stage.

- What materials are used?
  - back wall
  - wings
  - floor
  - ceiling
- Note on your plan the positions and number of:
  - electrical sockets
  - fixed lighting switches
  - fire safety equipment
- What structures are there for you to hang lamps from? Or are there portable tripods or stands to support lamps from?

Equipment inventory

You will also need to make a list of the equipment that is available to you for constructing your lighting and sound system.

- Lamps: note the type of lamp with the voltage and power rating.
- Microphones: note the type and the directionality.
- Speakers: what power rating and frequency range are they designed for.

Next Steps

You should now have the information you need to start planning your lighting and sound system.

If you have access to the computer software WYSIWYG
http://www.cast-soft.com/cast/software/products.jsp
you can prepare a plan of your performance area and try lamps in various positions.

Otherwise you may make a scale model of your space to try different lighting effects.

Teacher notes

This unit links to **AQA Unit 10 Physics of performance effects**.

For this unit students need to

produce a portfolio of evidence which considers how light and sound can be used in a performance and the science behind the design of a lighting and sound system in a performance you attended.

with the highest marks gained when

Through the portfolio, clear and thorough knowledge and real understanding of sound and light is demonstrated. Correct scientific terminology is used throughout to describe sound waves and light waves. This continues through to the description of the sound and lighting system used in the performance attended. There is a totally balanced performance across all three tasks in terms of the degree of coherence and clarity achieved.

Knowledge from the unit was fully applied in an appropriate manner across all the tasks. The knowledge gained was used to produce succinct designs for both the sound system (arrangement of equipment/venue and control systems) and the lighting set-up (lighting effects/control systems). A comprehensive evaluation of the performance was produced including details of the lighting and sound effects used in the performance attended. These details were presented in such a way that it is clear to see the science behind them. There was substantial evidence of the appropriate use of quantitative physical relationships in the preparatory research. Relevant calculations in relation to the speed of sound, intensity of light and the cost of the lighting arrangement in the performance attended were performed to a high degree of accuracy.

With relative autonomy, all the experiments conducted into light and sound were carried out to a high standard. The results obtained were of a consistently accurate standard. Equipment was used safely and skilfully to collect data to a high level of precision. Data was presented clearly and logically and is relevant to the designs produced.

Using plans and concepts with a firm foundation in science, comprehensive designs for both the lighting and sound system were produced. Results from the experiments conducted in relation to sound and light were fully documented and recorded to a high level of precision.

Two DVD ROM resources are required for this activity:

The MODEL project: Practical physics at work - available from the Institute of Physics

Engineering everywhere – available from 4science

If you have difficulty locating either of these, contact 4science.

admin@4science.org.uk telephone: 01722 411777 fax: 01722 411301

Task 1 Sounds Good

By completing this task students will produce notes and answers that will demonstrate that they can use the correct terms to describe sound.

By completing *Practical Sheet: Using a swept sine wave to investigate the acoustic behaviour of a room* students use their knowledge to describe different types of microphone.

The NCH tone generator can be downloaded for a free trial period from:

http://www.nch.com.au/tonegen/

The full version costs around £30

Audacity is freeware sound software and can be downloaded from:

http://audacity.sourceforge.net/

Answers to questions

Section 1

1 Students should include items such as: means for the audience to enter and leave (most theatres have a 'crush area' outside the performance arena), seating, performance area, backstage area for storage and props, support structures for lighting and sound equipment. You might also consider (for particular types of performance): the need for a back wall to reflect sound, roof and side walls to contain the sound, lavatories, access doors for stage equipment or stage 'flats'.

2 Students should consider both the shape of the walls and roof etc., but also the materials from which they are made – whether they reflect or absorb sound.

3 Students can see soft material upholstering the seats and wooden panelling on the walls. The seating material should enable the sound quality of the theatre to stay the same whether it has a small audience or is full. The wall panelling is designed to reflect sound, but also to diffuse those reflections.

4 The room has soft furnishings to provide some absorption. The walls include diffusing panels to limit the 'early' reflections that cause colouration of the sound.

5 The massive theatre wall reflects sound from the performance area back into the audience. The semi-circular shape of the auditorium retains the sound. Without an audience, the stone structures would cause a lot of reverberation, but with the audience in place, the acoustics would improve. The theatre performances, with a variety of events lasting all day, were provided free to the citizens of Orange, on public holidays specifically earmarked for theatre, so it was usually full!

Section 2

1 An anechoic chamber is one in which all reflections have been stopped. The reverberation time would be zero.

2 The walls are made of acoustic foam, which is designed to absorb sound efficiently. The pieces of foam are cut and arranged in a large variety of angles, so that any reflections that do occur are directed to further pieces of foam in which more absorption can take place.

3 Upholstery material, carpeting and curtains can be used to absorb sound. Irregularly shaped wall panels (and seating) are used to diffuse sound. The moveable ceiling reflects sound.

4 A swept sine wave is one that changes its frequency in a smooth fashion over a pre-determined range of frequencies in a particular time.

Section 3

1 The roof is lowered to give a smaller acoustic volume. The reflective baffles are removed from the stage and more absorbent materials used to decrease the reverberation.

2 In the 'theatre' mode, reflections are reduced so that speech may be heard more clearly. The sound is deader.

3 Reverberation is the persistence of a sound after the source of the sound has ceased. Reverberation time is the time it takes for the sound to die away. This is often taken to be the time it takes for the sound level to drop by 60 dB from the original.

Section 4

They mention trying speakers in different places, using a rug, having clutter or a bookcase in the room.

Task 2 Sound and Light

In this task students make further notes on the type and uses of microphones. They will also complete a data sheet on colour filters, which will provide the evidence of their understanding of the correct terminology to use when referring to colours and filters.

They will also make some simple calculations involving a theatrical lamp, which can be the model for those needed for the performance they attend.

For their portfolio, students are required to design a lighting set-up and control system for a performance, or part of a performance, of their choice including:

- the use of correct scientific terminology to explain the characteristics of light
- a calculation of the total cost of the lighting for a complete performance.

The first part of this task gives students practice in using the terminology associated with microphones, adding to the evidence from Task 1. The second part practises the use of terms associated with lenses, plus technical descriptions of colour, and an introduction to filters, which they may wish to use in their lighting design.

Watching the video and answering the questions posed should occupy no longer than one hour, although this may be extended if students undertake more research into microphones or colour.

The exercise involving filters in *Data sheet: Colour filters* could be extended, or preceded by work on colour mixing if that is appropriate, but this session is intended simply to familiarise students with the concept of wavelengths and their relationship to different colours.

The Lee filters website (http://www.leefilters.com/home.asp) shows data for many different colours that can be used to extend this exercise if required. They may be used as illustration of the colour components in different shades.

This is not data that can readily be used to illustrate the wave equation $v = f \times \lambda$, the numbers are too unwieldy. However, the link between wavelength, frequency and velocity could be explored if the mathematical dexterity of the group is good enough.

Answers to questions

Sound

1 Omni-directional microphones collect sound from all round the microphone in a relatively even way. Unidirectional microphones collect the sound from one direction, excluding sound from other directions.

2 The polar diagram (Fig 3) on page 2 is the best guide.

3 The characteristics show a response from 50 Hz to 15 000 Hz, with a level response between 100 Hz and 10 000 Hz. This compares with the human ear's response of approximately 25 Hz to 20 000 Hz (depending on age!). The level response is required for recording general voice and music.

Lighting

1 The lamp must be placed nearer to the lens than its principal focus. To produce a spot, the lamp will be moved back until it is very close to the principal focus. The 'spot focus' data shows light levels of 36500, 9125 and 4056 lux at 5, 10 and 15 metres. These are in the ratio 1 : 1/4 : 1/9

2 The filters illustrated in the Data Sheet are: A – red; B – blue; C – green; D – turquoise; E – lilac; F – magenta

3 (a) 3.4 amps; (b) UK mains voltage is 230V AC. A step down transformer would be needed; (c) 90 mins at 410 W or 0.615 kWh. (At 10p per kWh this would cost 6.2 pence.)

Venue check lists

These check lists will provide the details of the student's chosen venue that are required for their portfolio.

The complete *Sounds Good* video is about 18 minutes long, but can be shown in sections. With all questions this should occupy one double session, or up to 90 minutes.

This task is self explanatory. The principal issue for students is whether the venue they choose is a purpose designed performance area, with stage, lighting gantry etc., or whether it is an open space such as a sports, village or school hall that can be adapted for performance.

An ultrasonic or laser distance measuring device would be useful. The former can be purchased very cheaply. The latter are considerably more expensive, but will measure distances greater than the 15 or 20 m that the ultrasonic devices are limited to.

The WSIWYG software is a professional lighting design package. A demonstration version can be downloaded free of charge, but disables print and save options. An educational licence can be purchased for about £150.

http://www.cast-soft.com/cast/software/products.jsp

Some useful web links

http://www.theambassadors.com/miltonkeynes/info/seating_detail.html Seating plan for the MILTON KEYNES theatre

http://www.Milton Keynesweb.co.uk/MILTON KEYNEStheatre/DisplayArticle.asp?ID=6728 has two pictures showing the auditorium empty and with a full audience.

http://www.nch.com.au/tonegen/ Tone generator (shareware) can be used to generate a swept sine wave, which can then be played on Audacity http://audacity.sourceforge.net/

http://www.ultrasonic-ringtones.com/ Set of tones from 8 kHz upwards – amusing for students to test their teachers

http://www.shure.com/stellent/groups/public/@gms_gmi_web_ug/documents/web_resource/us_pro_sm58_ug.pdf Shure user guide for the SM58 mic shown in the *Engineering Everywhere* video.

http://www.theatre-antique.com/en/orange/298-discovery/ The wonderful acoustics of the Theatre in Orange

http://hyperphysics.phy-astr.gsu.edu/Hbase/acoustic/reverb.html Definitions and explanations of reverberation and reverberation time

http://www.harmony-central.com/Effects/Articles/Reverb/ An article on reverberation – the first part of which is appropriate for A-level.

http://www.micpool.com/The_Aural_Imagination.html Mic Pool is Director of Creative Technology at The West Yorkshire Playhouse Leeds. This site documents some aspects of his work. It includes step by step guide to sound design and sample designs, plus the sound system layout for the WYP.

http://www.getintotheatre.org/case_studies/mic-pool-director-of-creative-technology is a biography of Mic Pool

http://www.acoustics.salford.ac.uk/feschools/index.htm website for the 'Sounds Amazing' work

http://www.du.edu/thea/designs/Portfolio.html William Temple Davis designs – WTD is a theatre designer. This site has good photos of many of his sets, some with details of the numbers of lights etc.

http://www.d.umn.edu/~mharvey/crazyforyou.html The story of a how a lighting design was created for a production of 'Crazy for You'.

http://www.d.umn.edu/~mharvey/th1501a-z.html Effective lighting design A-Z

http://www.thestage.co.uk/connect/acblack/lightingfr.php An extract from the Stage Lighting Handbook