

ACTIVITY BRIEF

Investigating X-rays

The science at work

In hospitals and mobile radiography units, X-rays are used to allow doctors and other health workers to 'see' beneath the skin. X-ray imaging is a non-invasive technique, which means that surgery is not needed to examine a patient. The hazards of X-rays were discovered some time after X-rays were discovered. However, risks to patients and radiographers have been reduced by modern equipment, techniques and health and safety precautions.

Your brief

You will find out about X-rays and some of their applications in medicine. X-rays are high frequency (high energy) electromagnetic waves which can also be described as a stream of high energy photons. For safety reasons, you can't use X-rays in school or college. However, the principles of X-ray imaging are similar to the formation of shadows. You can learn a lot about X-ray imaging by investigating light shadows.

Task 1 Finding out about X-rays

In your notebook or file, describe:

- Where X-rays appear in the electromagnetic spectrum and their frequency range.
- How X-rays are generated – the basic structure of an X-ray tube.
- Hazards and risks associated with using X-rays. Include in your description:
 - the significance of the unit of dose equivalent (the sievert, Sv)
 - somatic effects: occur only in people exposed to radiation
 - hereditary (genetic) effects: occur in the offspring of people exposed to radiation
 - stochastic effects: occur randomly and are not unequivocally linked to radiation exposure, e.g. cancer
 - non-stochastic effects: unequivocally linked to radiation exposure.

Task 2 Investigating shadows

Use *Practical Sheet: Investigating shadows* to find out about:

- how X-ray images are captured
- how X-ray images can be improved by using narrow beams, grids and filters
- protection against exposure to X-rays.

Task 3 Modelling X-ray images of body tissue

Use *Practical Sheet: Modelling X-ray images of body tissue* to find out about:

- how X-rays differentiate types of body tissue (attenuation and contrast)
- using contrast media in X-ray imaging.

Task 4 Computerised axial tomography (CAT)

You may have heard of CAT scans. Find out about computerised axial tomography and write a brief description of how it works and what it is used for.

PRACTICAL SHEET

Investigating shadows

Radiographers use phantoms rather than real patients to test their X-ray equipment. A phantom is a simple model that mimics things that radiographers and doctors need to see to diagnose health problems. Imaging with X-rays can be mimicked using light. Use some simple phantoms to investigate magnification, contrast and sharpness.

Making the phantom

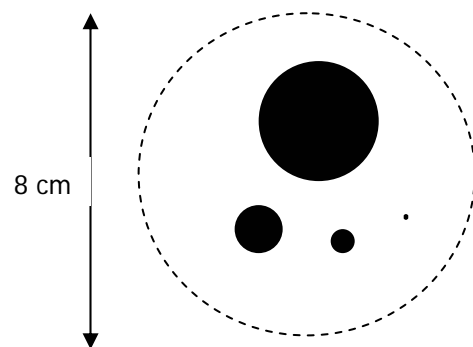
You can imitate material of different density by using acetate sheets with circles of various shades of grey printed on them. Print two acetates:

Acetate A

Print a grey circle, e.g. Gray 25% using Word, with approximate diameter 8 cm. This represents soft tissue of low density, e.g. fat or muscle.

Acetate B

Print a pattern of four black circles so that they fit within a circle of 8 cm diameter. The diameters of the spots might be 30 mm, 10 mm, 6 mm and 2 mm. These represent tissue of higher density such as a bone or surgical implants.



Make the phantom by laying *acetate B* on top of *acetate A* and holding them together with paper clips.

Beam width

Health and safety: Do not look directly at a lit light bulb. You can glance at it briefly if you are some distance away. The mains bulb will get hot. Remember, a risk assessment must be done before starting work.

Size of light source

Use two light sources:



Maglite solitaire



frosted (opaque) 60
or 100 watt light bulb

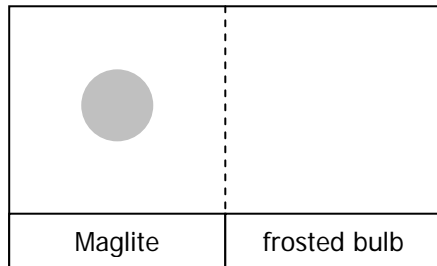
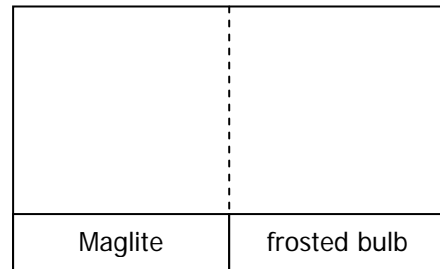
Use a ruler to measure the diameters of the two light sources. Record them in your notebook.

Investigating the effect of beam width on shadows

This must be carried out in a darkened room.

Divide a sheet of white A4 paper into two halves and label them as shown on the right. This is your screen.

Clamp the light source about 1 metre above the screen.



Hold the phantom between the light source and the white screen, about 10 cm away from the screen. Arrange it so that the shadow falls on the correct side of the screen. For example, see diagram on the left for when the Maglite torch is used.

Sketch around the shadow and make a note of any areas that are darker or lighter than others. Also record in your notebook:

- magnification – measure the size of the shadows and calculate the magnification
- contrast – describe how easily or not the circles on *acetate B* can be seen against the shadow from *acetate A*
- sharpness – describe the appearance of the edges of the shadows and estimate the extent of blurring.

Varying the position of the phantom

This must be carried out in a darkened room.

Now move the two acetates up and down between screen and light source. After you have experimented a little, choose three or four positions and record how magnification, contrast and sharpness depend on the relative positions of screen, phantom and light source.

Record your observations in a table similar to this:

	Distance between phantom and screen / cm	Magnification	Contrast	Sharpness
Maglite				
Frosted bulb				

Capturing the image

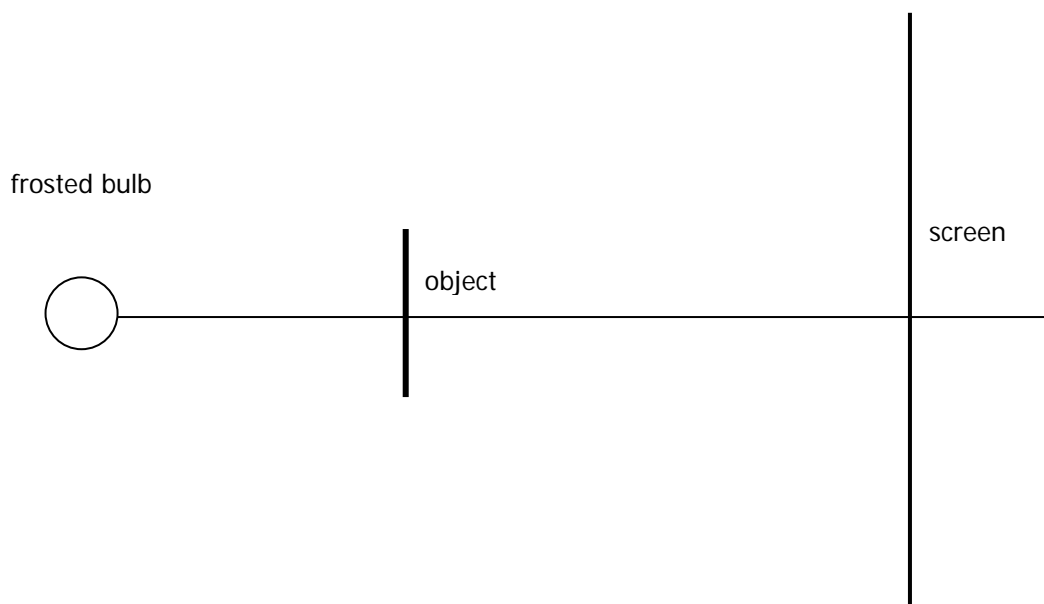
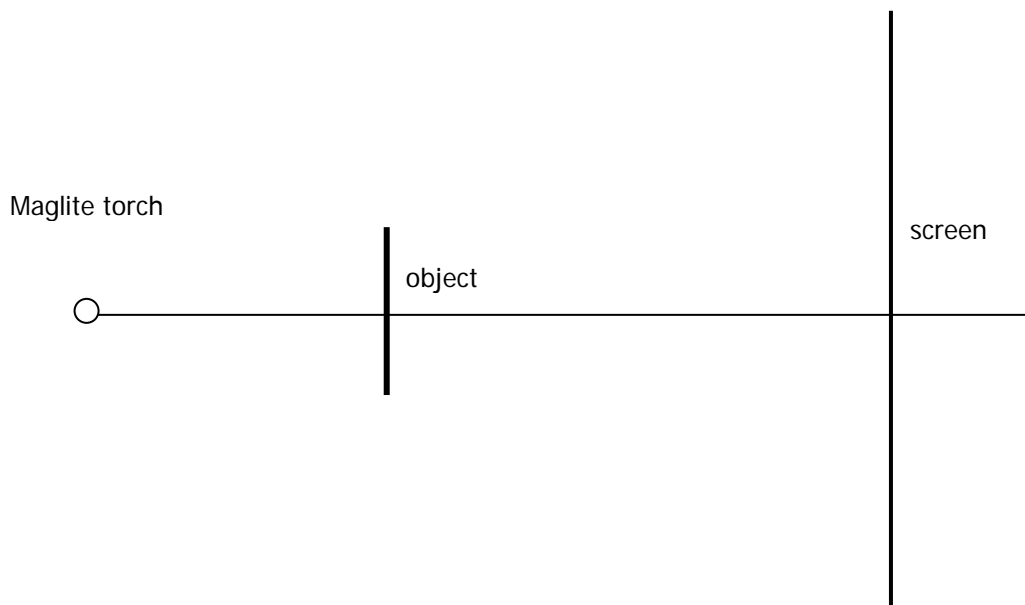
Attach a sheet of luminescent film to the back of the phantom, i.e. behind *acetate A*. Keep them in a large envelope in a dark place (e.g. a drawer) for about 30 minutes.

With the light source and screen one metre apart, turn off the lights. Take the phantom and luminescent film out of the envelope and hold against the screen with the phantom facing the torch. Then ask your partner to turn on the torch for 10 seconds. With the lights still out, remove the phantom and look at the luminescent film.

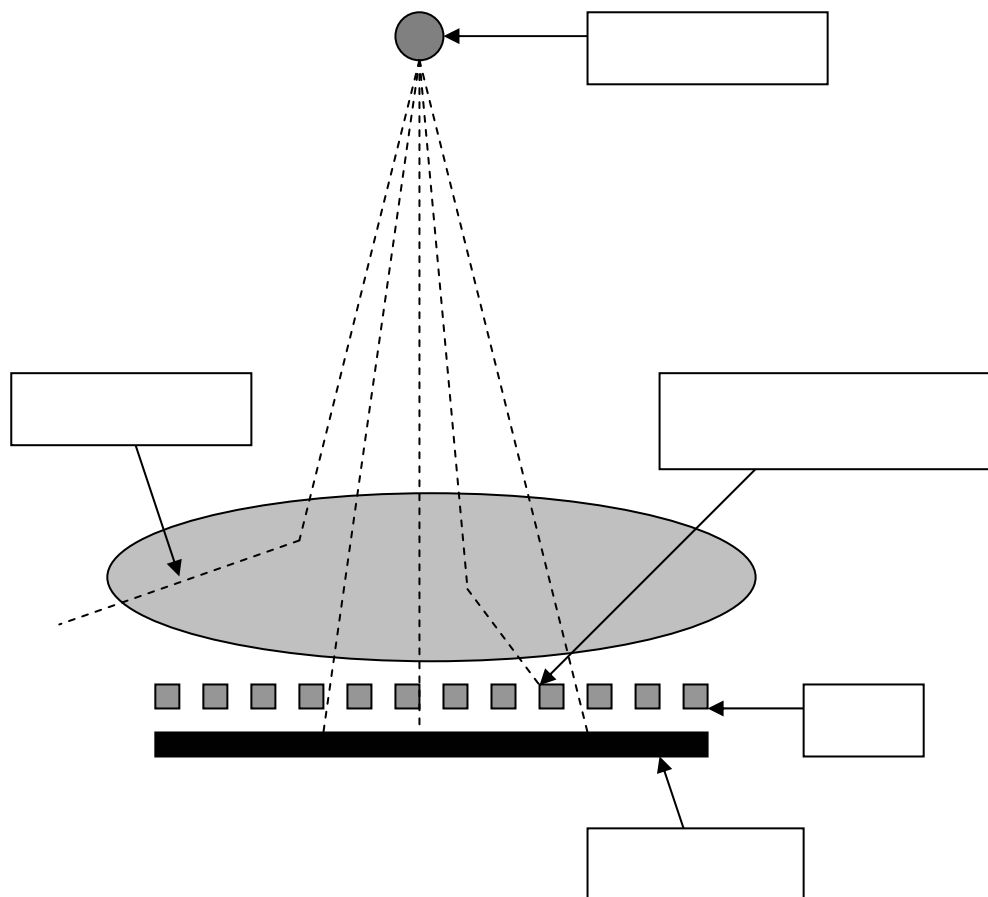
Record your observations.

Interpreting your findings

- 1 In your notebook, draw two ray diagrams to show the ideas of magnification and sharpness. Draw one for light from a source that is almost a point source, e.g. the Maglite torch, and one for a broad light source, e.g. the frosted bulb. In each diagram, draw at least two rays on each side of the object.



- 2 Based on the results of your investigation explain why a narrow beam of X-rays is preferred to a wide beam.
- 3 Two other techniques are used to improve X-ray imaging: X-ray grids and X-ray filtration.
 - a An X-ray grid is a series of lead strips placed in front of the X-ray film. They improve imaging by stopping scattered X-rays from reaching the film. This is shown in the diagram below. Copy the diagram into your notebook and write suitable labels in the boxes. The oval shape represents the object being X-rayed.

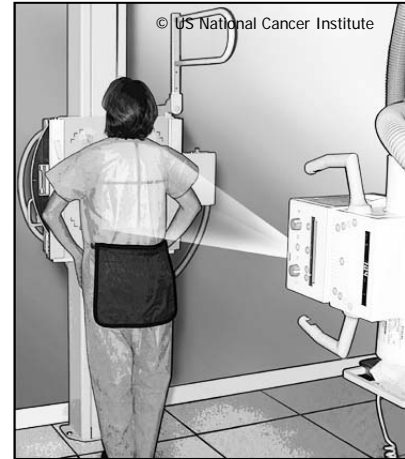


- b X-ray photons have a range of energies. The proportion of high energy X-rays can be increased by filtering the beam through a metal plate. In radiography, aluminium plates, a few millimetres thick, are commonly employed.
 - i. Why is it good to filter out some of the X-rays? (see question 6)
 - ii. Why is aluminium sheet used rather than lead?
- 4 X-rays trigger chemical reactions in photographic film, just as light does in ordinary cameras. So film exposed to X-rays looks like a photographic negative. Look at the X-ray of a chest on the right.
 - a What are the light grey areas?
 - b How does the appearance of an X-ray photograph differ from the shadow images you obtained in your experiment?
 - c Why does using luminescent film to capture the image of the shadows better mimic X-ray photographs than simply shadows cast on a piece of paper?



- 5 Look at the picture on the right. It shows a person having a chest X-ray.

Based on your experiments, explain why the patient is pressed against the X-ray film and the X-ray source is further away.



- 6 Radiographers and others who may be near X-rays wear protective clothing. These are usually 'lead aprons'.

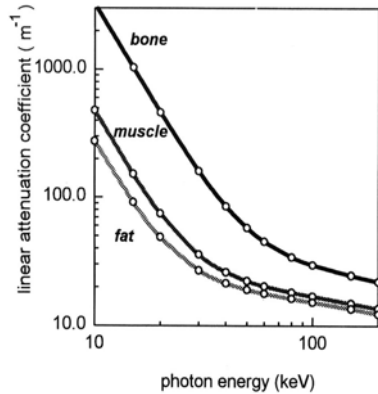
Find out about the dangers of using X-rays and how the extent of damage caused depends on:

- a the part of the body exposed
- b the dose received
- c the rate at which it is received
- d the importance of using the lowest effective dose.

Low energy X-rays may be used if an image-intensifier is also used. This means lower X-ray doses can be used on patients. The intensifier makes the image produced by low energy X-rays easier to see.

PRACTICAL SHEET

Modelling X-ray images of body tissues



This follows on from *Practical Sheet: Investigating shadows*.

Body tissues absorb, and thereby attenuate, X-rays to varying extents. It depends on the density of the tissue. Fat attenuates X-rays slightly less than muscle. Bone, however, attenuates X-rays much more.

Further, the density of some tissue changes with age. For example, women's breast tissue becomes less dense when they are past child-bearing age.

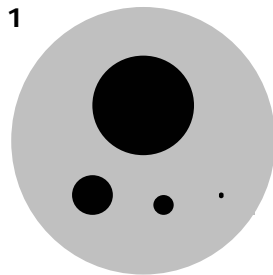
As before, you will use acetate phantoms to investigate the challenges for radiography. Different phantoms are made by combining different acetate sheets.

Making the phantoms

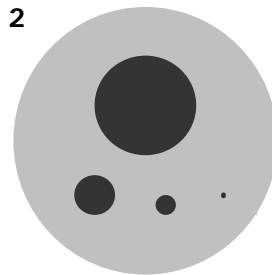
Acetates **A₂₅** and **A₄₀** represent background tissue, e.g. fat. Each is a single 8 cm diameter circle on an acetate sheet, printed as Gray 25% (**A₂₅**) and Gray 40% (**A₄₀**).

Acetates **B₁₀₀**, **B₈₀** and **B₅₀** represent tissue that a radiographer might be looking for, e.g. bone or a tumour. Each has 30 mm, 10 mm, 6 mm and 2 mm circles on an acetate sheet, printed as Black (**B₁₀₀**), Gray 80% (**B₈₀**) and Gray 50% (**B₅₀**).

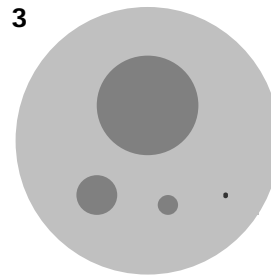
Make six phantoms by using these combinations of acetates:



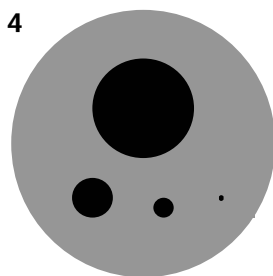
Acetates **A₂₅** + **B₁₀₀**



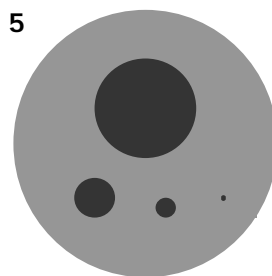
Acetates **A₂₅** + **B₈₀**



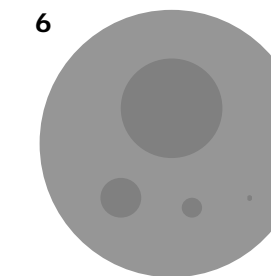
Acetates **A₂₅** + **B₅₀**



Acetates **A₄₀** + **B₁₀₀**



Acetates **A₄₀** + **B₈₀**



Acetates **A₄₀** + **B₅₀**

Investigating the phantoms

This must be carried out in a darkened room.

Do not look directly at a lit light bulb. You can glance at it briefly if you are some distance away. The mains bulb will get hot. Remember, a **risk assessment** must be done before starting work.

Clamp a Maglite torch about one metre above an A4 sheet of white paper to act as a screen.

For each combination of acetates (**1-6**), hold the pair of acetates between the light source and the white screen, about 10 cm away from the screen. Sketch around the shadows and indicate areas that are darker or lighter than others.

Keep your drawings for each of the combinations in your notebook. Beneath each drawing, note differences in the shadows in terms of contrast and sharpness.

Now move the pairs of acetates backwards between screen and light source. Choose three or four positions and use a clean sheet of white paper to sketch around the shadows formed at these positions. Annotate your drawings. Beneath each, sketch a labelled diagram to show the position of the screen, phantom and light source.

Note how contrast and sharpness depend on the relative positions of screen, phantom and light source.

Interpreting your findings

- 1 Mammography is the use of X-rays to identify tumours in women's breasts. Breast tissue is mainly fat. Healthy tissue and cancerous tissue in tumours have similar densities.

The problem is more acute with young women. Their breast tissue tends to be denser than older women's and even more similar to that of a tumour.

- a Why does this make it difficult to diagnose them using X-ray imaging?
- b Which phantom best models this situation?

With age, breast tissue becomes fatter (it has fewer glands), so slightly less dense. While its density is still similar to a tumour, the difference is sufficient to enable meaningful mammograms to be obtained.

- c Which phantom best models this situation?

Write a paragraph to explain why it is more difficult to diagnose breast cancer in young women than in older women. Make sure you use these terms:

attenuation – a measure of how much a material absorbs X-rays

contrast – the ease with which one shadow can be differentiated from another.

- 2 Bone is a living, growing tissue that turns over (is lost and regenerated) at a rate of about 10% per year. Its composition is:

10% collagen (a protein), 10% water and 80% calcium phosphate (a mineral)

The combination of collagen and calcium phosphate makes bone strong and yet flexible enough to bear weight and to withstand stress. A typical value for the density of bone is 1.9 g cm^{-3} , but the density of bone mineral is 3.32 g cm^{-3} . The density of fat is 0.9 g cm^{-3} and the density of muscle is 1.1 g cm^{-3} .

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- a Explain why bone can be seen so clearly in X-rays.
- b Which of the phantoms you made best models an X-ray of the bones in your fingers?



3 Look at the X-ray of a titanium hip replacement.

- a Why does the implant show up white on the X-ray?
- b What is the area immediately around the implant and why is it a lighter shade than the areas surrounding it?
- c What is the black area at the top left of the X-ray?



4 Soft tissue doesn't always show up clearly in an X-ray. To image certain organs and blood vessels, radiographers use contrast media - liquids that attenuate X-rays (by absorbing them) more effectively than neighbouring tissue. For example, (i) a patient may be given a 'barium meal' if the radiographer wants to examine the digestive system, (ii) a contrast medium may be injected into a patient's bloodstream if the radiographer wants to image blood vessels.

- a What is a 'barium meal' and how does it work?
- b Cancer Research UK advises patients:

Your doctor will watch on an X-ray screen as the barium passes through your stomach and duodenum. Any growths or ulcers will show up on the screen. The couch will be tipped into different positions during the test to make the barium flow where the doctor wants it to go..

Design a simple experiment using light shadows to demonstrate this process.

Teacher notes

This activity relates to:

- **AQA Unit 8 Medical physics**
- **OCR Unit 16 Working waves**

Both units are **externally assessed**. Therefore, there is no compulsion for practical work. However, this activity provides a practical investigation that should help students understand the principles of X-ray imaging.

These are the relevant parts of the units' specification:

AQA Unit 8 Medical physics

Students should know:

- *that X-rays are high frequency electromagnetic waves*
- *the dangers of using X-rays and how the extent of damage caused depends on the part of the body exposed, the dose received, the rate at which it is received, and the importance of using the lowest effective dose*
- *the difference between stochastic and non-stochastic effects, the difference between hereditary and somatic effects and be familiar with the sievert (Sv) as the unit of dose equivalent*
- *the precautions taken by radiographers when using X-rays to protect both themselves and the patient*
- *how X-rays are produced, including the basic structure of an X-ray tube*
- *how X-ray images are formed (exposure of photographic film) and the meaning of the terms attenuation and contrast*
- *how contrast media can be used to enhance X-ray images*
- *what CAT scans are, how they produce images and how they differ from standard X-rays*
- *how CAT scans are similar to, and different from, MRI scans*
- *some situations where X-rays are a good diagnostic technique and, by considering the different attenuation effects of different tissues, be able to explain why X-rays are suitable for diagnosing some conditions but not others*
- *be able to evaluate the use of X-rays and CAT scans in specified situations.*

OCR Unit 16 Working waves

Students need to:

- *state qualitatively the differential absorption of X-rays by air, fat, other soft tissues and bone and the appearance of X-rays on film after passing through these media*
- *explain techniques for improving quality of X-ray images; use of a grid, narrow beam, filtration*
- *explain how X- and γ -radiations damage cells through ionisation*

- *evaluate the consequent health hazards and identify the radiological protection measures taken in X- and γ -ray imaging and radiotherapy treatment areas, to monitor and minimise the dose received by staff and the damage done to healthy tissue of patients; the half-thickness value of lead screening used*
- *describe how the use of image-intensifying screens reduces dose rates*
- *describe how CAT scanners can produce much more detailed information than conventional X-rays*

The formation of shadows using white light provides a useful analogy to X-ray image formation.

Remember, a risk assessment must be done before starting work. Tell students not to look directly at a lit bulb. Mains bulbs will get hot.

In *Investigating shadows*, the key trends are:

- magnification depends on distance of phantom from the screen and the light source; the nearer to the light source and/or further from the screen, the greater the magnification
- contrast depends on the nature of the light source (the smaller the light source the better) and the distance of phantom from the screen and the light source; the nearer to the light source, the less good the contrast.

In *Modelling X-ray images of body tissue* these ideas are reinforced. Further, the issue of attenuation and contrast is investigated in detail. Students will see that the more similar the greyness of two phantoms, the lower the contrast in their images. Therefore, this second part also shows that:

- the sharpness of the shadow depends on the same variables as contrast.

In *Investigating shadows* students need to be able to see the shadows of the black smaller circles within the shadow cast by the large light grey circle.

With the acetate held just 1 cm from the screen students will see little if any difference between shadows formed by the point source (torch) and the wide source (light bulb).

However, as the acetates are moved away from the screen:

- image size: the magnification increases for both light sources
- contrast: shadows of the smaller circles should become harder and harder to see, eventually disappearing. The smallest circle disappears first. In other words, the contrast decreases.

This is more noticeable for the frosted light bulb than with the Maglite torch. In other words, the Maglite torch continues to show contrast even when the phantom is being moved away from the screen and nearer to the light source.

In trial experiments it was found that all four circles from **B** could be seen with the phantom 25 cm from the screen using the Maglite torch, but only the largest black circle could be seen using the frosted bulb.

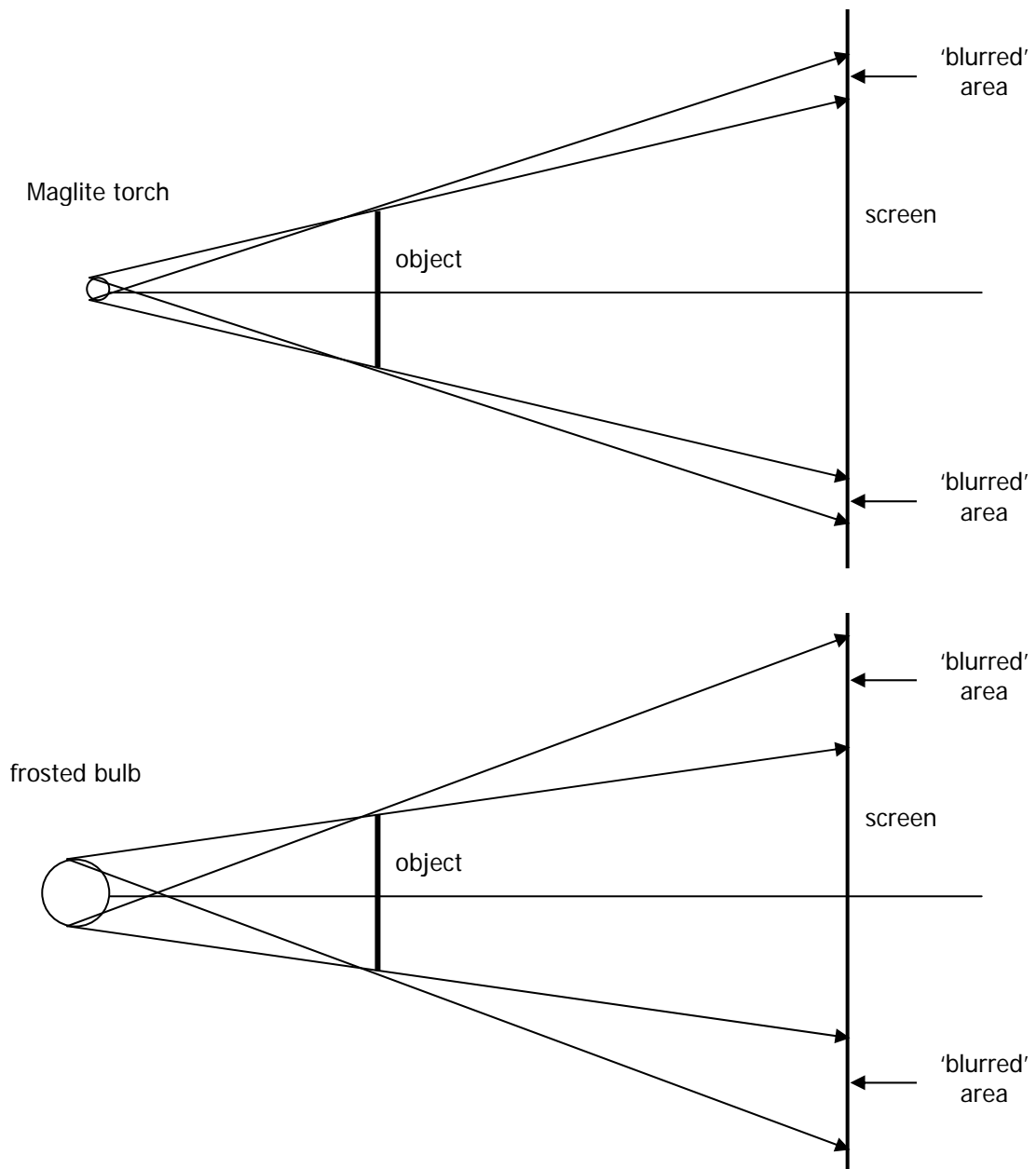
- sharpness: the same trend was observed as for contrast.

In trial experiments, blurring increased hugely as the phantom was moved closer to the frosted bulb, but only slightly with the Maglite torch.

Answers to questions

Practical sheet: Investigating shadows

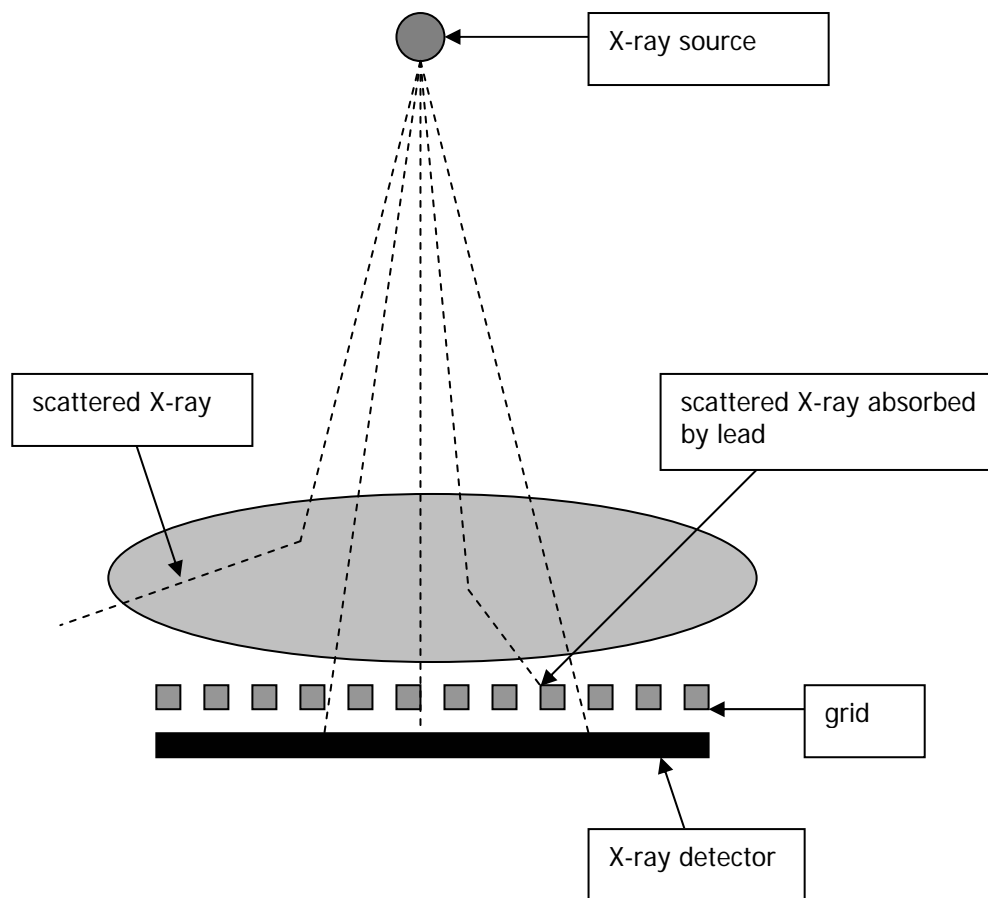
1 The ray diagrams should be similar to these:



It can be seen that the sharpness of a shadow depends on the diameter of the light source.

2 A narrow beam of X-rays will produce a sharper image.

3 a



b

- i. to reduce the effective dose and, therefore, reduce the risk of over-exposing the body to X-rays
- ii. lead might absorb too much of the X-radiation, depending on its thickness.

4 a bone

b its in 'reverse', in other words light areas rather than dark shadows

c it 'converts' dark shadows into light areas on the film

5 To obtain maximum sharpness of the X-ray image

6 Students need to do appropriate research (see, for example, the 4science Revision Guide for AQA A2 GCE Unit 8 Medical physics, p 36-39)

Practical sheet: Modelling X-ray images of body tissue

1 a Because the healthy tissue and cancerous tissue have such similar densities that X-rays cannot distinguish between them

b 6 (least difference in densities)

c 3 (tumour tissue is same as before, but surrounding breast tissue is less dense)

2 a Bone has a much higher density than fat or muscle

b 1 or 4

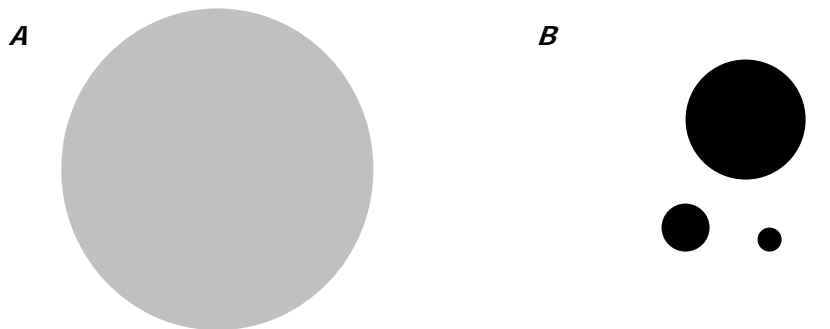
- 3 a Titanium is much higher density than any tissue, including bone
- b Bone, which is more dense than the surrounding tissue
- c Background against which the X-ray has been taken, i.e. not part of the leg
- 4 a A suspension of barium sulfate in water
- b The experiment might involve watching the changing shadow of a dark liquid running through colourless, transparent plastic tubing or glass tubing.

Equipment and materials

Practical sheet: Investigating shadows

Each pair of students will need

- small Maglite torch, e.g. Maglite Solitare (<http://www.maglite-torches.co.uk/?gclid=CJWH46qvsogCFSgYZwodMiVWzQ>)
- frosted (pearl) 60 watt light bulb (100 watt light bulb could be used), with bulb holder (will need PAT testing)
- clamp stand
- sheets of white A4 paper
- metre ruler and small ruler
- acetate sheets with the following patterns on them



Acetate A should have a single grey circle, approximate diameter 8 cm. One should be slightly darker grey than the other.

This can be made by laser-printing from a Word document in which the circle has been filled in with 'Gray 25%'.

Acetate B should have four black circles arranged so that they fit with a circle of 8 cm diameter. The diameters of the spots might be: 30 mm, 10 mm, 6 mm and 2 mm.

- luminescent film, e.g. glow-in-the-dark from <http://www.mutr.co.uk/prodDetail.aspx?prodID=554>
- two paper clips
- large envelope.

Practical sheet: Modelling X-ray images of body tissue

Each pair of students will need

- small Maglite torch, e.g. Maglite Solitare (<http://www.maglite-torches.co.uk/?gclid=CJWH46qvsogCFSgYZwodMiVWzQ>)
- frosted (pearl) 60 watt light bulb (100 watt light bulb could be used), with bulb holder (will need PAT testing)
- clamp stand
- sheets of white A4 paper
- metre ruler and small ruler
- acetate sheets with the following patterns on them
 - two acetates to represent background tissue, e.g. fat. These are made as **A** above. Each is a single 8 cm diameter circle on the acetate sheet, printed as:
 - Gray 25% (**A₂₅**) – this is the same as acetate A in *Investigating shadows*
 - Gray 40% (**A₄₀**).
 - three acetates to represent tissue that a radiographer might be looking for, e.g. bone or a tumour. These are made as **B** above. Each has 30 mm, 10 mm, 6 mm and 2 mm circles on an acetate sheet, printed as
 - Black (**B₁₀₀**) – this is the same as acetate B in *Investigating shadows*
 - Gray 80% (**B₈₀**)
 - Gray 50% (**B₅₀**)

However, different degrees of greyness and circle sizes could be experimented with.