STEM ACTIVITY 6
TEACHER NOTES

STEREO IMAGES

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EQUIPMENT REQUIRED PER PAIR OF STUDENTS:

- A cheap cardboard virtual reality viewer (eg Google cardboard) with lenses removed
- The two convex/bi-convex lenses from the cardboard viewer
- Another two identical convex/ bi-convex lenses with a longer focal length and of same or slightly bigger diameter to those in the viewer (eg glass lenses with a 4 cm diameter and focal length of 20 cm).
- White paper or card to form a screen
- Graph or squared paper
- Blu-tack
- Two different coloured pens or pencils
- Adhesive or masking tape
- Scissors
- A copy of the Stereo Diagrams
- Mobile phone with camera

PREPARATION REQUIRED

You may need to download the accompanying video *Reconnaissance: The Cold War*. You will also need to remove the two short focal length lenses from the virtual reality viewer.

PHYSICS CURRICULUM LINKS: LENSES, CAMERAS, THE EYE

STEM ACTIVITY: CAMERAS AND 3D IMAGES

In this activity, students investigate how the size and brightness of an image created by a lens depends on its focal length and investigate how we can see things in 3D.

Introduce the activity by playing the accompanying video: *Reconnaissance: The Cold War*. If students are unfamiliar with lenses, introduce them as curved transparent blocks that focus light to create an image. The lens in a camera is used to focus an image onto a photographic film or CCD array. The lenses in our eyes focus an image onto our retinas.

Students should follow the STEM instructions to investigate how size and brightness of an image formed by a lens depends on the focal length. They should start with the fat (short focal length) lens and hold it a few centimetres away from a piece of paper attached to a wall. Moving the lens back and forth will allow them to bring an image of a distant object (eg a window) into focus (see figure 1).

FIGURE 1: IMAGE FORMED BY THE FAT LENS

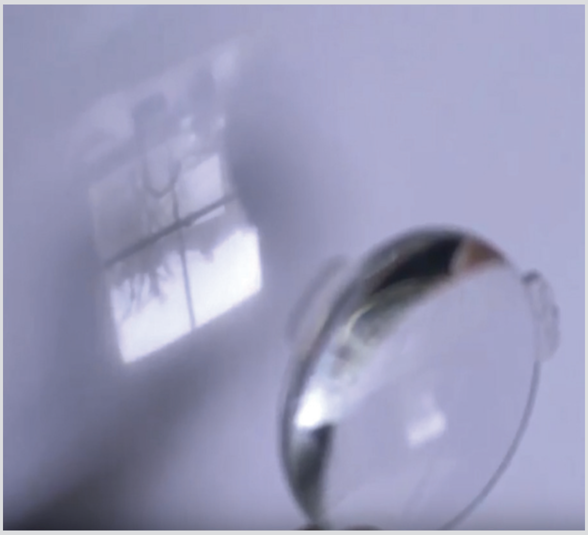

Image of a window focussed onto a sheet of paper using a lens from a virtual reality viewer (4.5 cm focal length).

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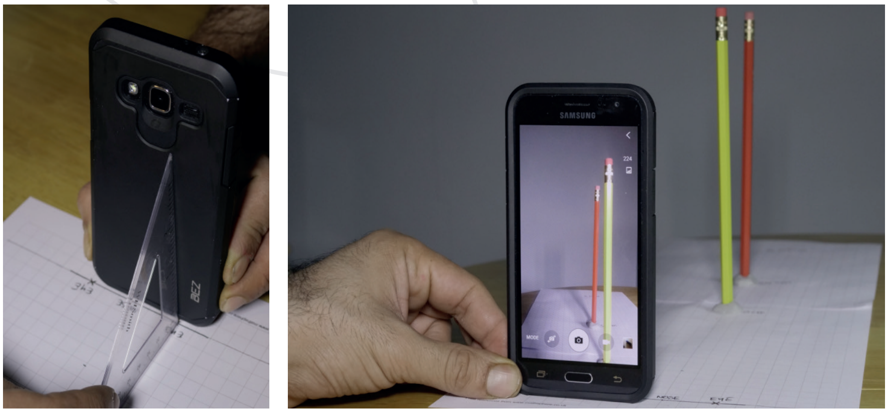
FIGURE 2:
TAKING STEREO PHOTOGRAPHS

Aligning the lens of camera to one of the eye positions using a set square and taking a photograph from the left eye position.



To determine the focal length students should work in pairs. One of them should bring the image into focus while the other measures the distance between lens and image. They will need to do this for both the fat and thin lens and record their results and observations by drawing a diagram. There is no need to draw ray diagrams. They only need to record lens and image positions and indicate which image is brighter or dimmer, larger or smaller.

They should then discuss which type of lens would be better suited for a camera used in aerial reconnaissance. A short focal length lens has a smaller lens-to-image distance. It can be used to make a smaller camera which is easier to mount on an aircraft. A long focal length lens creates a bigger image on which it is easier to see more detail (the photograph has a higher resolution because the image is spread over more pixels on the film/CCD). In reconnaissance seeing details is critical. Lenses with long focal lengths are better.

In the second part of the activity students will need their mobile phones to take stereo photographs. Still working in pairs one of them should place a ruler across their partner's forehead and estimate the distance between the centres of their partner's eyes (the pupillary distance). They should then stick two sheets of graph paper together and mark the left and right eye position along one of the short edges of the sheet. They will need a set square to align the camera lens on their mobile phone to each eye position and some blu-tack to stand two different coloured pencils upright on the graph paper (see figure 2).

They should then discuss how their photos differ and suggest how they relate to our ability to perceive depth. When one photo is compared to the other there appears to be a shift of the position of the pencils. The size of the apparent shift (parallax) depends on the distance of the objects from our eyes and our brain exploits this fact (and other cues from the environment) to estimate the distances to objects.

For the final part of the activity they should mount the two long focal length lenses in the cardboard viewer to make a stereoscopic viewer. Using a small piece of tape at opposite corners of the lenses will secure them in place. They should hold the viewer above the *Stereo Diagrams* at a distance equal to the focal length of the lenses in order to see a 3D effect. Not all students may be able to see the effect. Some hints on how to maximise their chances are described on the STEM activity instructions.

Finally, they should consider the advantages of stereo photographs over using a map or single photograph. Maps are more likely to be out of a date. A single photograph only provides one view of an object. In aerial reconnaissance taking stereo photographs allows 3D viewing which makes it easier to judge the height and nature of an object.

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ABOUT STEREOSCOPES AND PHOTOGRAMMETRY

Depending on students' age and aptitude, you may want to include more discussion about how the dimensions of objects can be calculated from aerial photographs and why stereoscopes are used to view them.

The principles of aerial stereo photography are illustrated in figure 3. A single camera is used to take two overlapping photographs in quick succession as the aircraft flies over the landscape. The resulting photographs display a parallax due to the motion of the aircraft.

Although it is possible to view the stereo photographs directly, without lenses, this can lead to eye strain. Focusing on nearby objects for a long time requires keeping the eye muscles contracted. The lenses in stereoscopes make the objects photographed appear to be far away as this allows the eye muscles to remain relaxed (see figure 4).

In contrast to modern virtual reality viewers, the lenses in stereoscopes need to be quite far away from the image. Modern viewers can use short focal length lenses because mobile phone screens provide their own source of light. The lens can be mounted in small light proof units. Stereoscopes in contrast rely on light being reflected off a physical copy of the image and there needs to be a large enough gap between the lens and photograph to allow the photograph to be illuminated. Stereoscopes need relatively long focal lengths lenses.

Although three-dimensional viewing may make it easier to identify which objects may be of interest, viewing alone doesn't provide accurate indications of the size of a photographed object. Accurate determinations of dimensions require taking measurements of the photographs and considering geometry.

The principle for finding distances is illustrated for a single photograph in figure 5. The lens-to-image distance is equal to the focal length (f) of the lens and the lens-to-object distance is equal to the height of the aircraft above the ground (H). The distance between two objects on the ground can be worked out by measuring the distance between them on the photograph and scaling it by multiplying by H/f.

For objects that are off-centre on the photo, the vertical dimensions can also be worked out. When the image of a tall building is projected onto the flat surface of the photographic film the building will seem to "lean out"- it will show what is called a radial displacement. By measuring the radial displacement (r) and the distance of the building from the centre of the photo (x), the height of the building (Y) can be determined (see figure 6).

FIGURE 3: STEREO PHOTOGRAPHS FROM THE AIR

A stereo pair of photographs can be taken using a single camera from a moving aircraft.

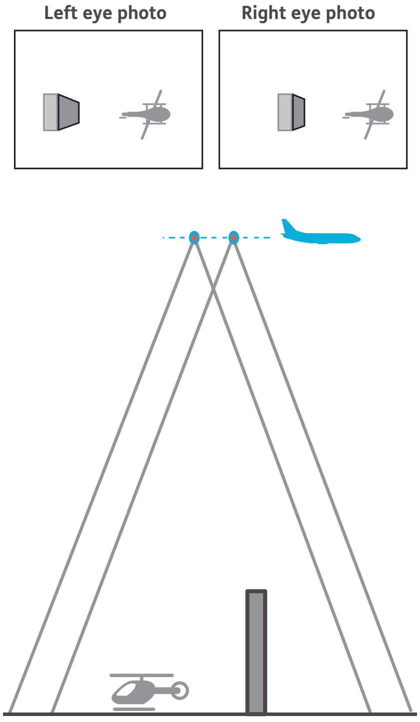
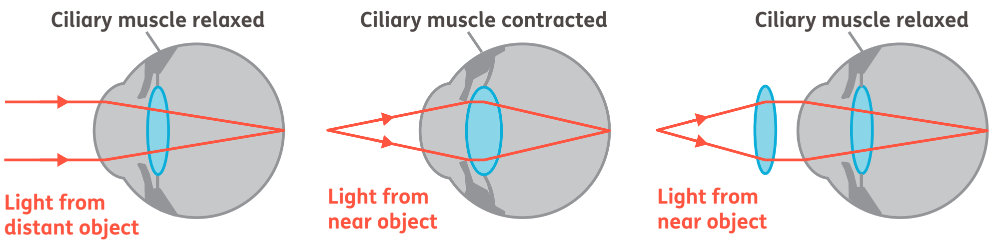


FIGURE 4: THE EYE

In the eye, the ciliary muscle adjusts the shape of the lens. When viewing far away objects the lens is thin and the muscle is relaxed. When viewing nearby objects the lens is fat and the muscle is contracted. Using a lens in front of the eye allows the image of a nearby object to be viewed with the muscle in the relaxed position.



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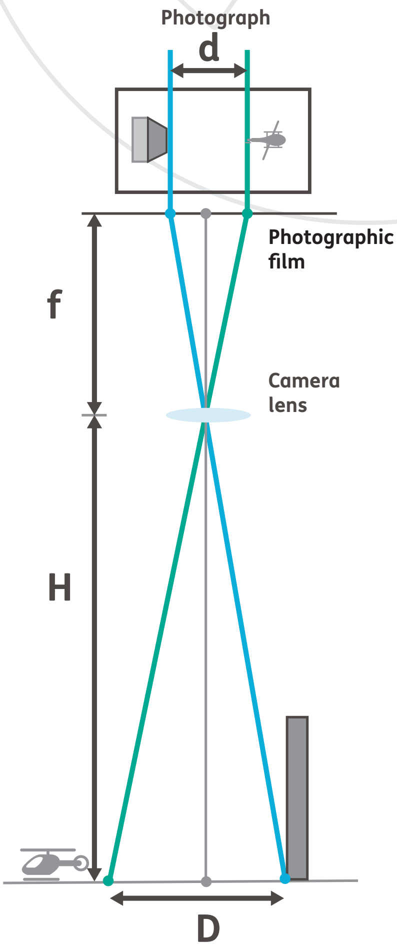

FIGURE 5: WORKING OUT DISTANCE

The triangles above and below the lens are similar: D/d=H/f. Re-arranging gives the formula for working out distances on the ground from those in the photo.

Distance

$$D = \frac{Hd}{f}$$

Example

A photograph is taken from an aircraft flying at a height of 2 km using a camera with a 10 cm focal length. If a runway measures 5cm on photo what is the actual length of the runway?

D =
(2000m x 0.05m) / 0.1 m
= 1000m

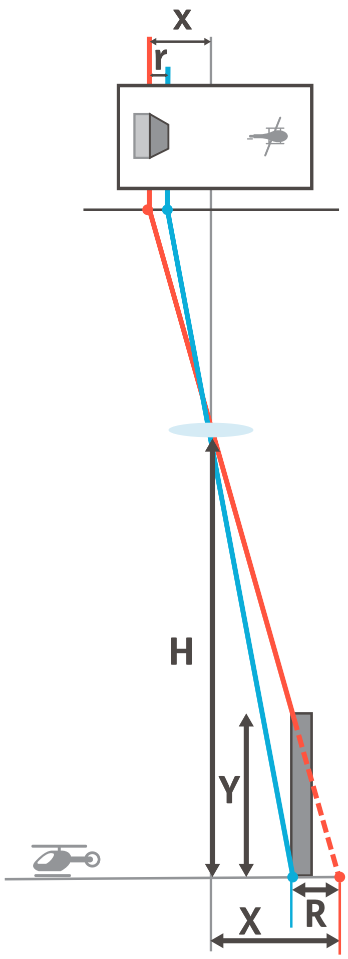

FIGURE 6: WORKING OUT HEIGHT

The radial displacement (r) of a building depends on the distance from the centre of the photo (x). The ratio of distances along the ground are the same as the ratio of distances in the photo: X/R = x/r. And, because the triangles are similar, Y/R = H/X. Combining these two expressions allows the height of the building to be determined.

Height

$$Y = \frac{Hr}{x}$$

Example

A photograph is taken from an aircraft flying at a height of 2 km. If a building is 10 cm from the centre of a photo and shows a radial displacement of 1 mm what is height of the building?

Y =
(2000m x 0.001m) / 0.1m
= 20m

FURTHER INFORMATION

Students can find other images to print for viewing by searching online for "stereo pairs". For information about teaching ray diagrams see Supporting Physics Teaching (14-16): **bit.ly/RAF-Ray**. For other optics experiments visit the Practical Physics Website: **bit.ly/RAF-Optics**