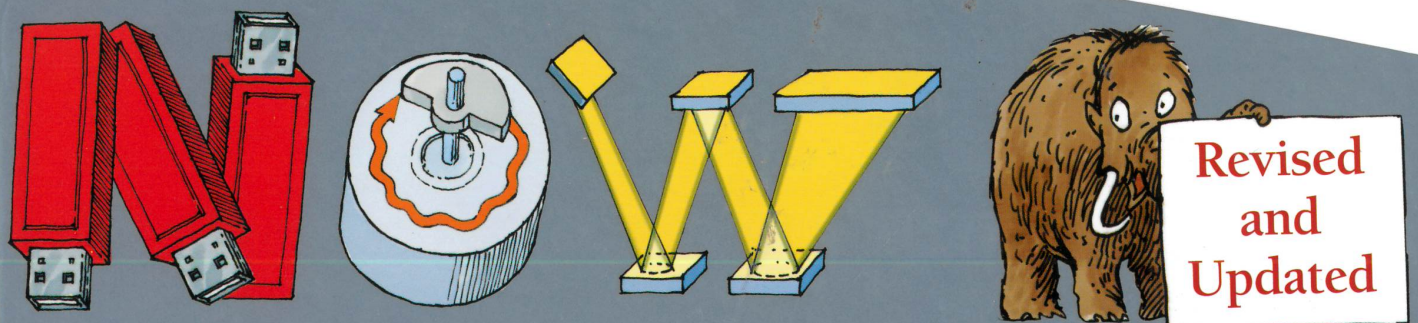
DAVID MACAULAY

THE WAY THINGS WORK NOW



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FROM LEVERS TO LASERS, WINDMILLS TO WI-FI,
A VISUAL GUIDE TO THE WORLD OF MACHINES

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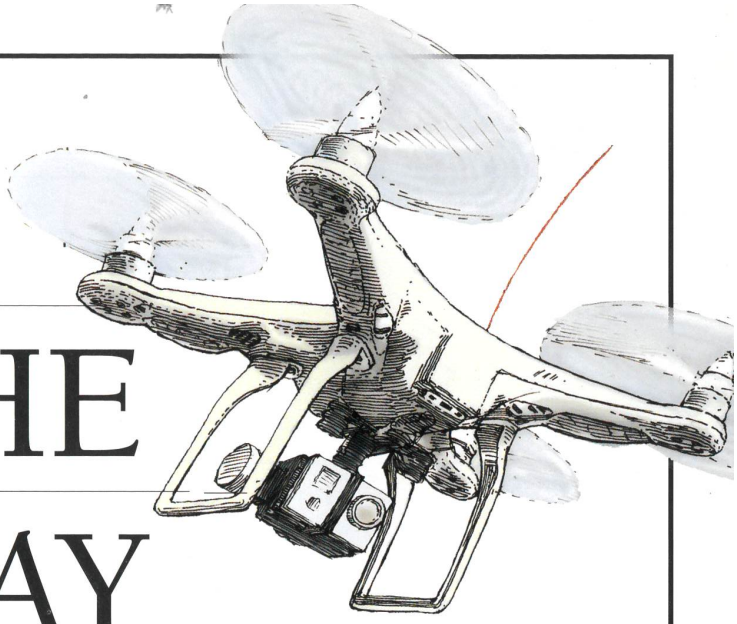
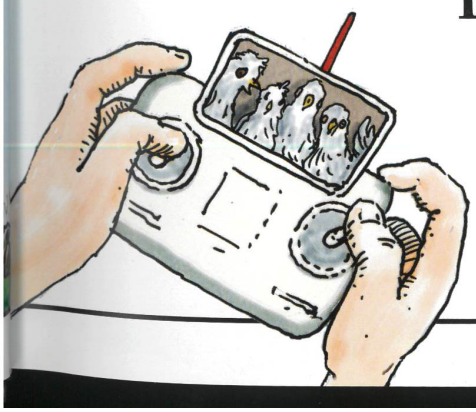


THE WAY THINGS WORK NOW

FROM LEVERS TO LASERS, WINDMILLS TO WI-FI,
A VISUAL GUIDE TO THE WORLD OF MACHINES

DAVID MACAULAY
WITH NEIL ARDLEY



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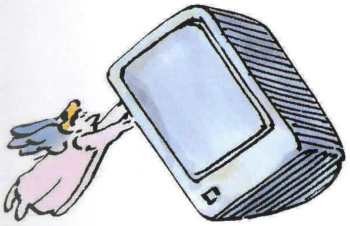

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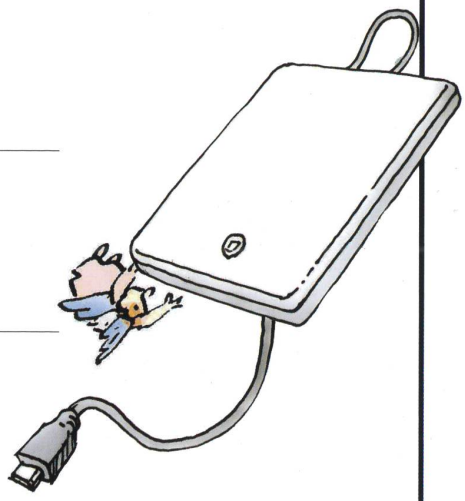

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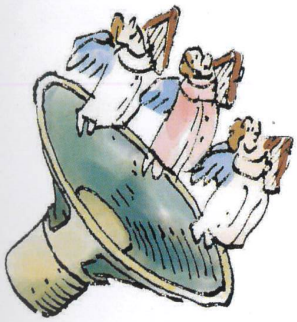

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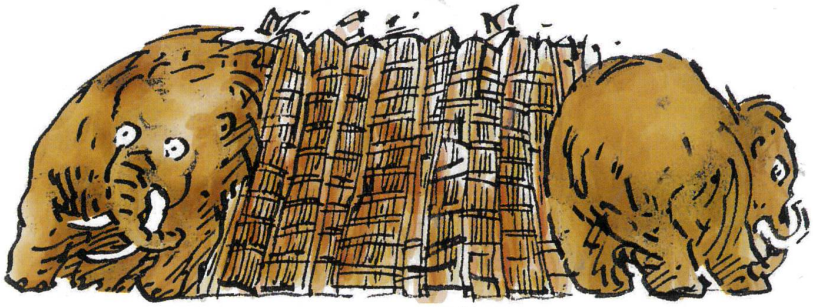

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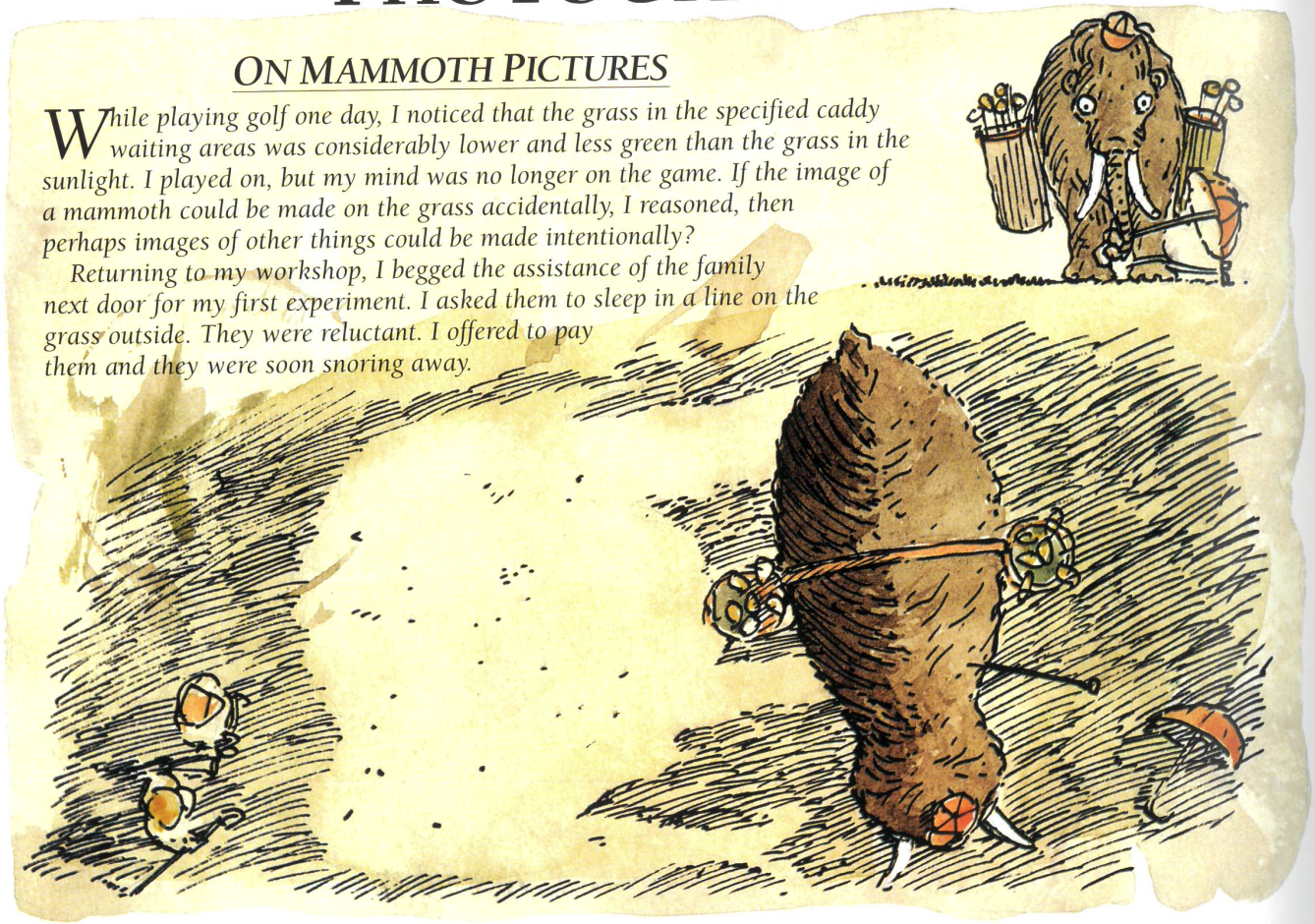
PHOTOGRAPHY

ON MAMMOTH PICTURES

While playing golf one day, I noticed that the grass in the specified caddy waiting areas was considerably lower and less green than the grass in the sunlight. I played on, but my mind was no longer on the game. If the image of a mammoth could be made on the grass accidentally, I reasoned, then perhaps images of other things could be made intentionally?

Returning to my workshop, I begged the assistance of the family next door for my first experiment. I asked them to sleep in a line on the grass outside. They were reluctant. I offered to pay them and they were soon snoring away.

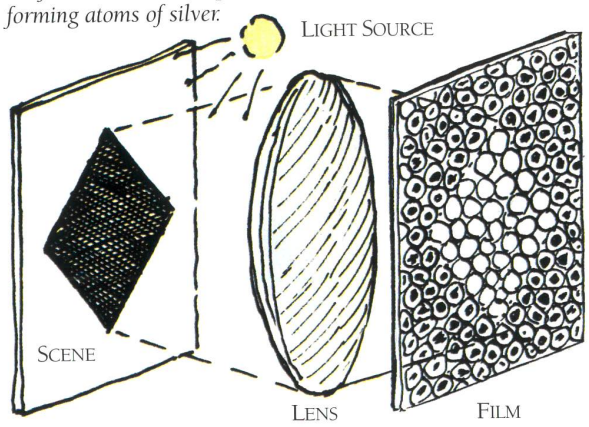


PRESERVED IN SILVER

Film photography uses silver, rather than grass, to preserve images. Light-sensitive compounds of silver on the plastic film break down when exposed to light. The result is tiny specks of silver wherever light has fallen—the image preserved on the film. The film has to be developed, to make more silver form where the film has been exposed. This makes a "negative," because light areas of a scene are represented by dark silver areas on the film. The whole process has to be repeated, this time with photographic paper instead of film, to form a positive image.

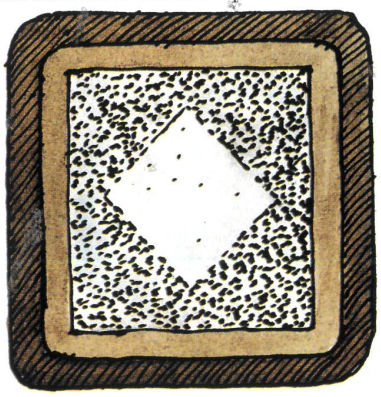
EXPOSURE

Where the light from the bright parts of an image reaches the film, the silver compound begins to break down, forming atoms of silver.



DEVELOPMENT

A chemical called a developer causes visible grains of silver to form wherever the dark silver atoms are present.



NEGATIVE

The negative image is then projected onto photographic paper, the process repeated to produce a positive image.

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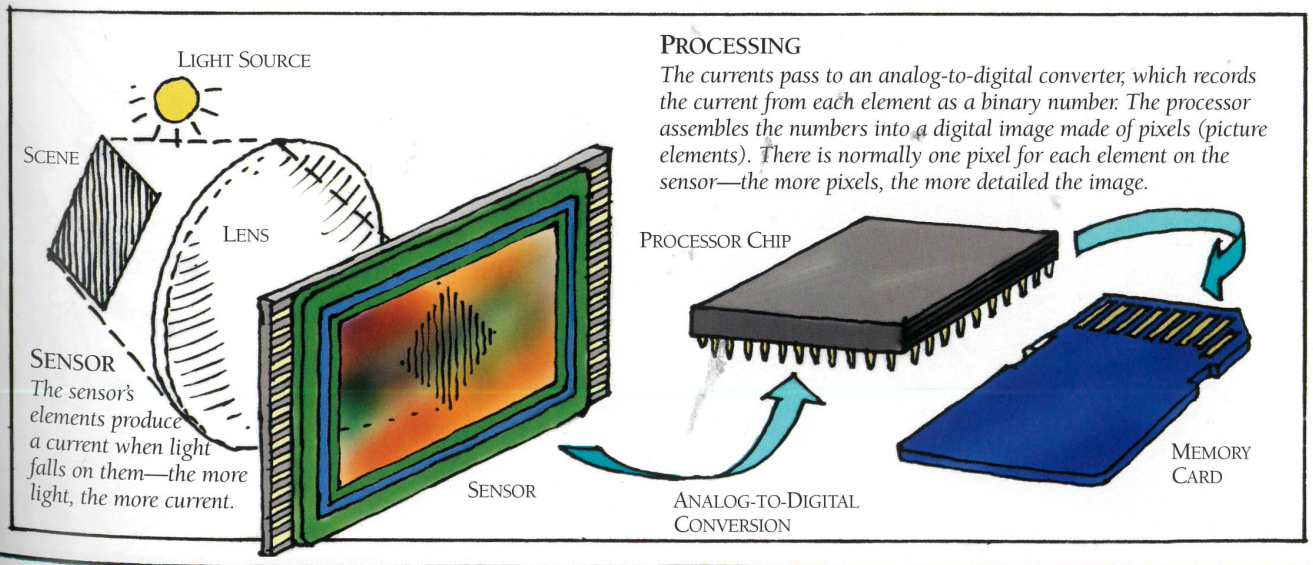
I had them return for the next five days and lie in exactly the same spot. By the end of the week I had a perfect image of my neighbors. The procedure soon caught on, and eventually even school groups could be seen lying motionless on the workshop's lawns.

However, several drawbacks arose that I had not foreseen. The images required continuous trimming once the subjects left the picture. They were also difficult to display as well as being astronomically expensive to frame. Had I been able to shrink people before they were recorded, I am convinced that my discovery would have had a bright future.

DIGITAL PHOTOGRAPHY

Most photography today is digital. An electronic sensor instead of film captures the image. The sensor has a grid of thousands or millions of light-sensitive elements, and is connected to the camera's battery. Light falling on an element causes that element to allow electric current to flow—the brighter the light, the greater the current. The electric currents then pass through an analog-digital converter (see p. 322) and an image processor, forming a digital image, which is stored on a removable memory card (see pp. 334-35).



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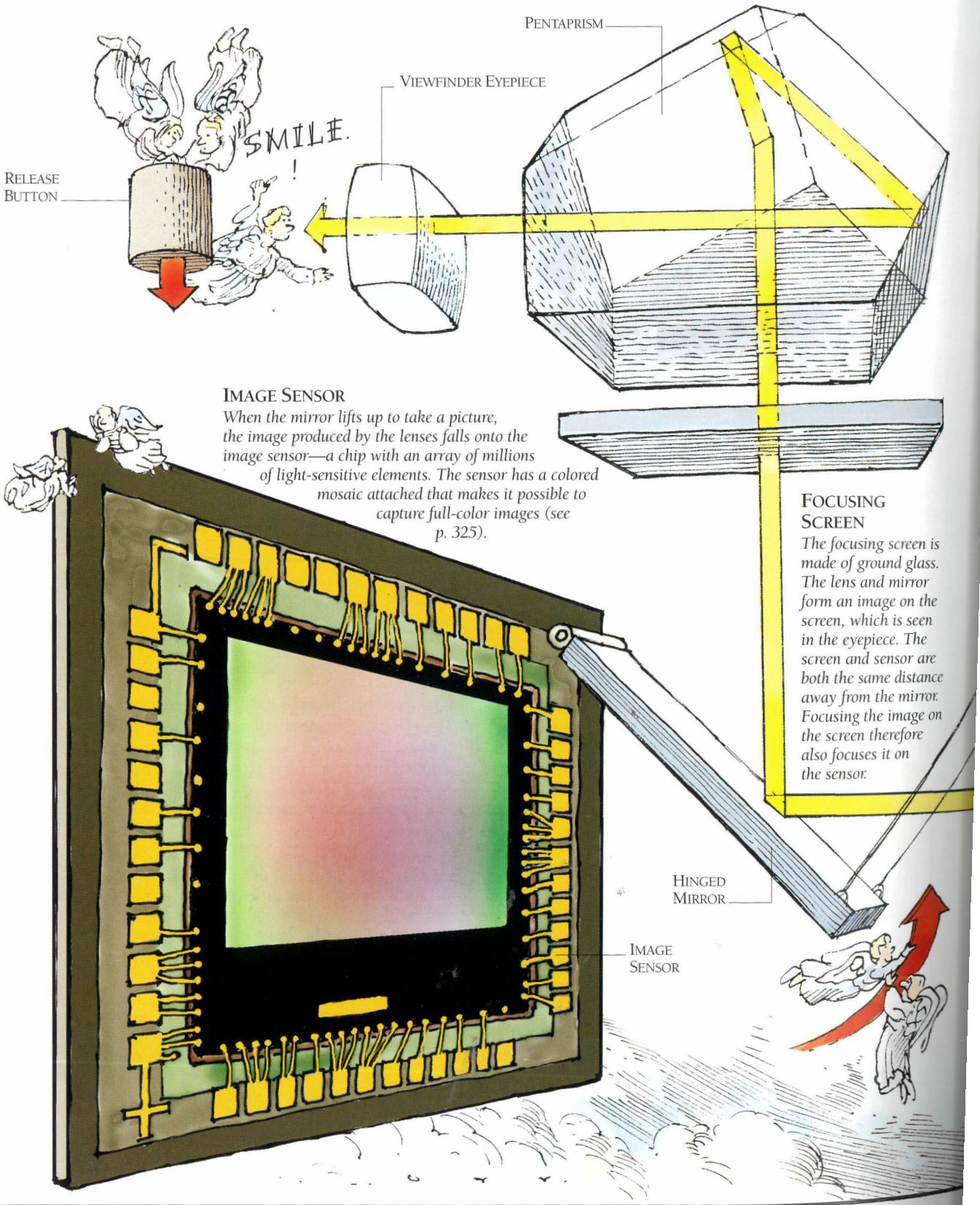
DIGITAL SINGLE-LENS REFLEX CAMERA



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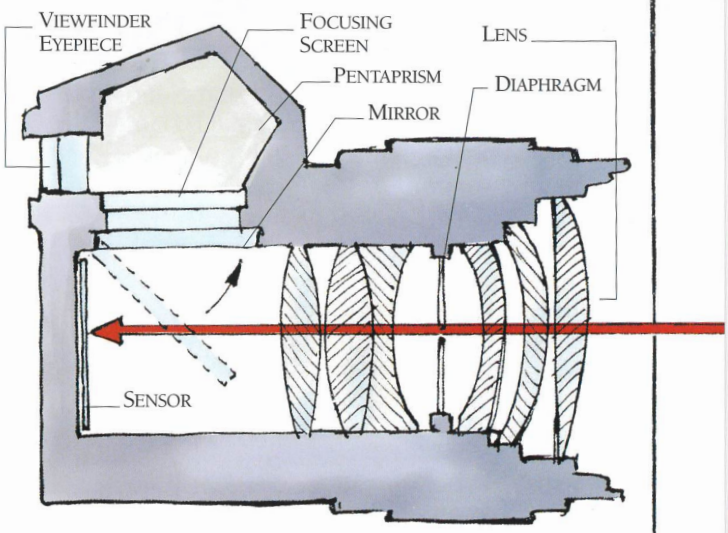
Some cameras have two different sets of lenses: one to view the image and one to throw it onto the image sensor. Many photographers prefer to view the actual image that will fall on the sensor before taking a picture. The digital single-lens reflex (DSLR) camera is so named because it uses a single collection of lenses for viewing and for taking the picture. A hinged mirror, angled at 45 degrees in front of the sensor, reflects the light beam from the lens onto a focusing screen above the mirror. The image forms on this screen, and light from it is reflected by the faces of a pentaprism (five-sided prism) into the viewfinder eyepiece. The various reflections turn the viewfinder image upright and the right way around. When the shutter release is pressed, the mirror rises and the light beam strikes the sensor.



IRIS DIAPHRAGM

The diaphragm controls the aperture of the lens, regulating the amount of light that enters the camera. A set of hinged blades move to open or close the central hole. A small aperture produces sharper images, with more of the scene in focus. A wider aperture allows through more light, which is useful in low lighting.

LENS

A high-quality lens is made up of several lens elements that work together to form a sharp image on the sensor. Some of the elements can move back and forward to focus the image, and to zoom in and out. These precise movements are achieved using stepper motors (see p. 283). The lens surfaces are often coated to reduce reflections.

LIGHT BEAM

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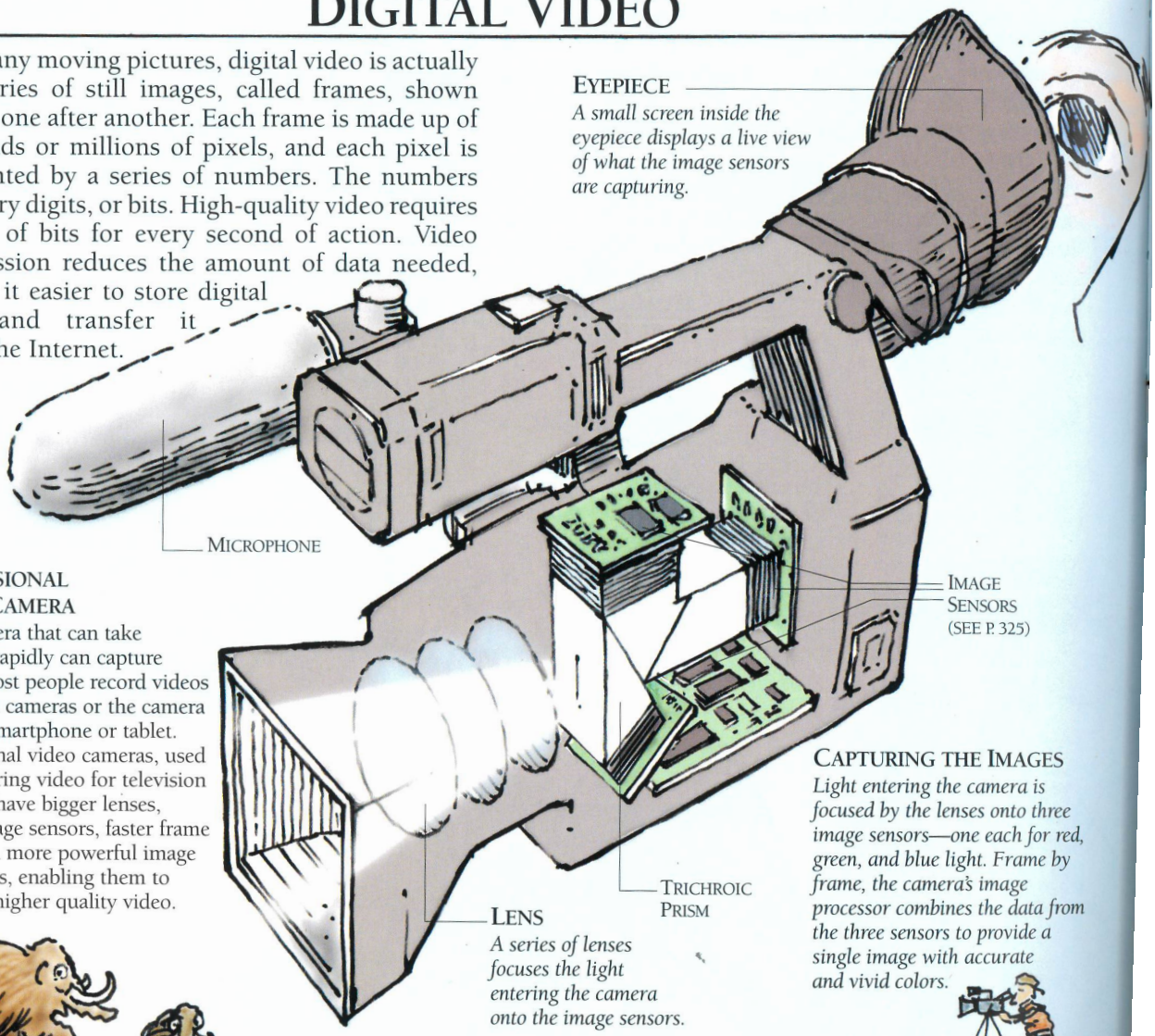
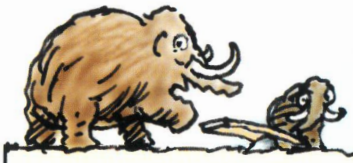
DIGITAL VIDEO

Like any moving pictures, digital video is actually a series of still images, called frames, shown quickly one after another. Each frame is made up of thousands or millions of pixels, and each pixel is represented by a series of numbers. The numbers are binary digits, or bits. High-quality video requires billions of bits for every second of action. Video compression reduces the amount of data needed, making it easier to store digital video and transfer it across the Internet.



PROFESSIONAL VIDEO CAMERA
Any camera that can take pictures rapidly can capture video. Most people record videos on digital cameras or the camera in their smartphone or tablet. Professional video cameras, used for capturing video for television or films, have bigger lenses, larger image sensors, faster frame rates, and more powerful image processors, enabling them to produce higher quality video.

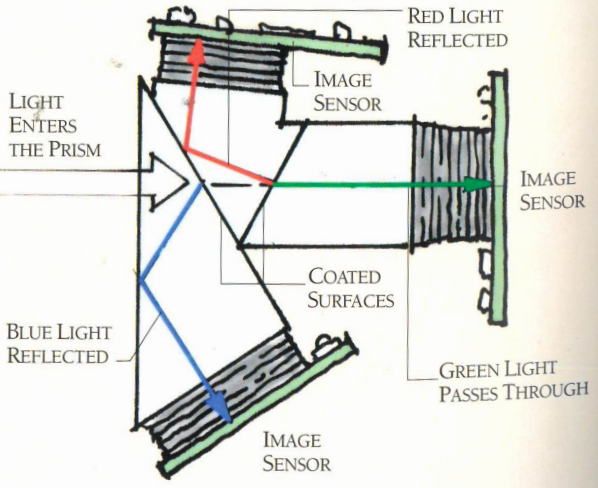
CAPTURING THE IMAGES
Light entering the camera is focused by the lenses onto three image sensors—one each for red, green, and blue light. Frame by frame, the camera's image processor combines the data from the three sensors to provide a single image with accurate and vivid colors.



SEPARATING COLORS

A color digital image is actually made up of three images—one red, one green, and one blue. Most cameras have a single sensor, with a checkerboard filter of red, green and blue squares (see p. 325).

Many professional video cameras have a trichroic (three-color) prism arrangement instead, which splits the image into three, sending each image to its own sensor. Inside the prism the light meets surfaces with special coatings that reflect light of certain colors, but allow the rest of the light to pass through.



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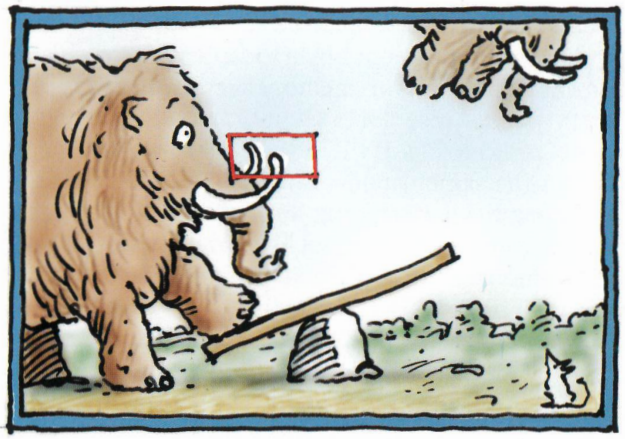
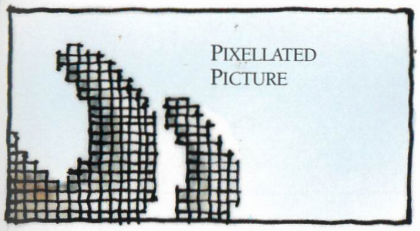
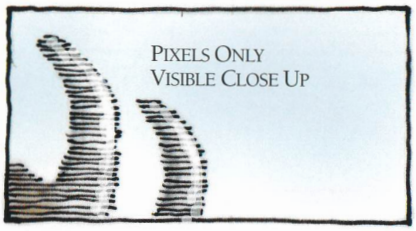
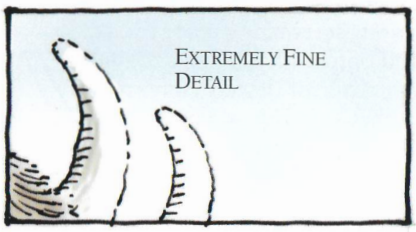
PICTURE QUALITY

Pixels are the tiny elements that together form the picture you see on the screen. The more pixels each frame has, the more detail will be present in that frame, and the clearer the video will be. The dimensions of a video image, in terms of the number of pixels along the horizontal and vertical edges, is called its resolution. Most modern televisions can display video at a resolution of 1920 x 1080. The higher the resolution, the more bits are needed to represent each frame.









LOW RESOLUTION

On low resolution video, such as videos streamed across a slow connection to the Internet, the pixels may be clearly visible.

HIGH DEFINITION (HD)

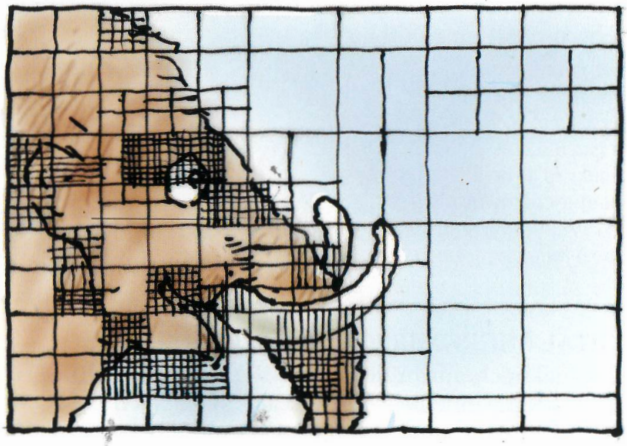
A standard HD television picture is 1920 x 1080. Some TVs can display ultra-high definition (UHD), up to 3840 x 2160.

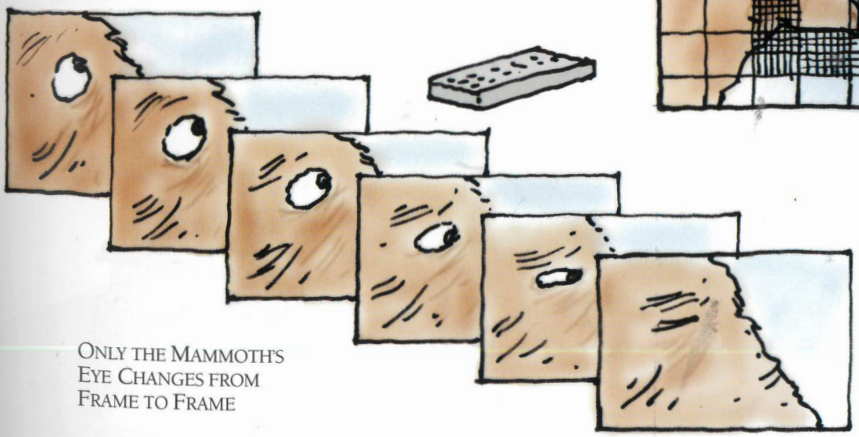
4K RESOLUTION

Digital video displayed in cinemas is typically 4096 x 2160, called 4K. The images are extremely clear and lifelike.

VIDEO COMPRESSION

High-quality digital video requires billions of bits every second, quickly filling up a hard disk or memory card (see pp. 334-35). The camera's image processor "compresses" the video, so that it takes up much less space. It uses a code to represent areas of each frame that are very similar, and areas that change little from frame to frame. The code requires far fewer bits than the raw image. A processor in a television or computer can then use the same code to reconstruct the frames for display.





ONLY THE MAMMOTH'S EYE CHANGES FROM FRAME TO FRAME

TIME AND SPACE

Video compression saves space in digital storage media, such as memory cards. Large areas of this frame are almost identical and can be represented as blocks of a single color.

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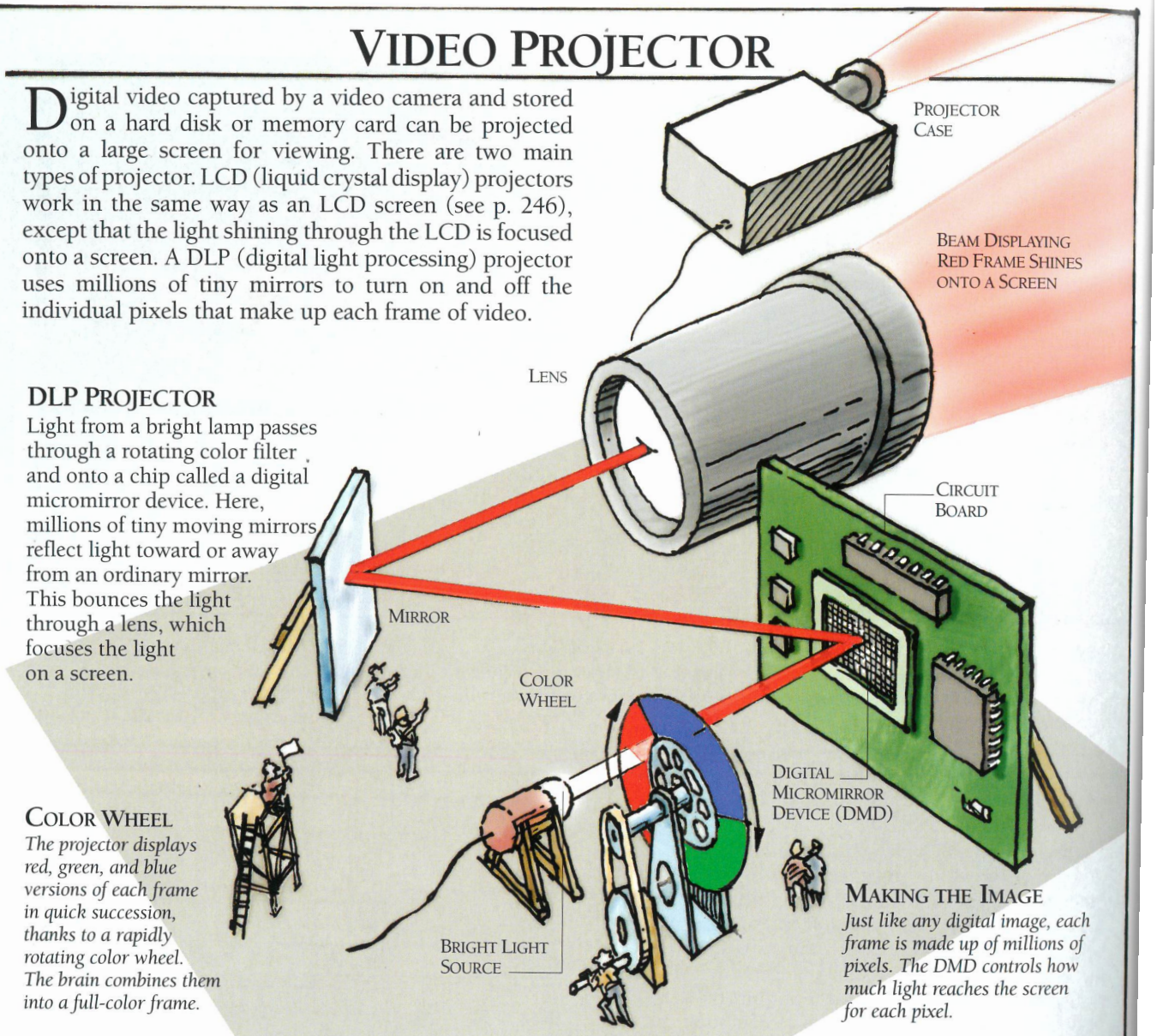
VIDEO PROJECTOR

Digital video captured by a video camera and stored on a hard disk or memory card can be projected onto a large screen for viewing. There are two main types of projector. LCD (liquid crystal display) projectors work in the same way as an LCD screen (see p. 246), except that the light shining through the LCD is focused onto a screen. A DLP (digital light processing) projector uses millions of tiny mirrors to turn on and off the individual pixels that make up each frame of video.



DLP PROJECTOR

Light from a bright lamp passes through a rotating color filter and onto a chip called a digital micromirror device. Here, millions of tiny moving mirrors reflect light toward or away from an ordinary mirror. This bounces the light through a lens, which focuses the light on a screen.

COLOR WHEEL

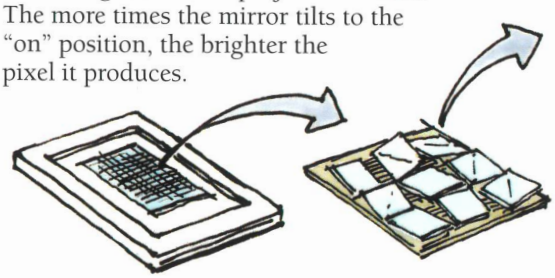
The projector displays red, green, and blue versions of each frame in quick succession, thanks to a rapidly rotating color wheel. The brain combines them into a full-color frame.

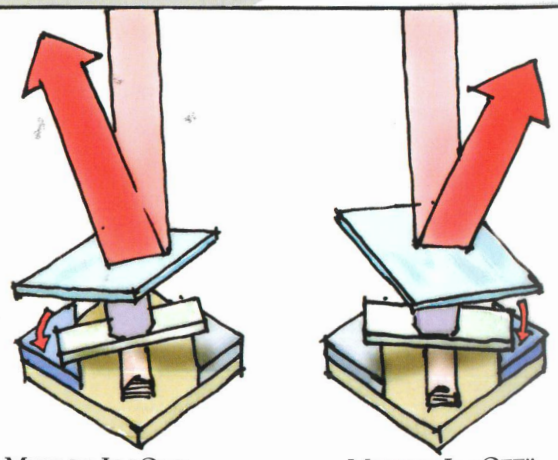
MAKING THE IMAGE

Just like any digital image, each frame is made up of millions of pixels. The DMD controls how much light reaches the screen for each pixel.

DIGITAL MICROMIRROR DEVICE

The digital micromirror device (DMD) is covered with millions of tiny mirrors—one for each pixel of a frame. The mirrors are hinged, and tilt back and forth thousands of times a second, directing light toward or away from the projector's main mirror, which reflects light onto the projection screen. The more times the mirror tilts to the "on" position, the brighter the pixel it produces.





MIRROR IS "ON"

Micromirror reflects light onto the projector's main mirror.

MIRROR IS "OFF"

Micromirror reflects light away from the projector's main mirror.

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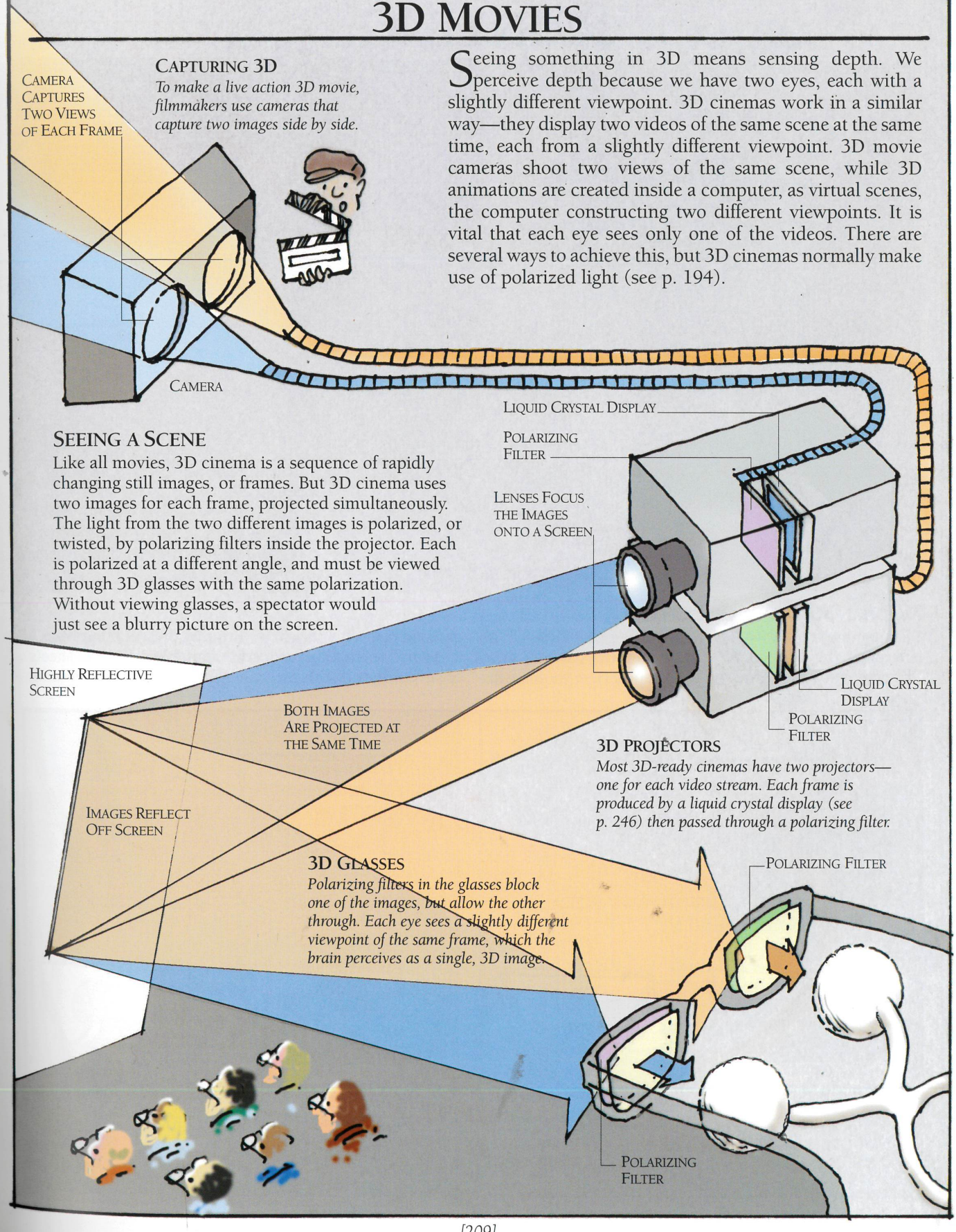
3D MOVIES

Seeing something in 3D means sensing depth. We perceive depth because we have two eyes, each with a slightly different viewpoint. 3D cinemas work in a similar way—they display two videos of the same scene at the same time, each from a slightly different viewpoint. 3D movie cameras shoot two views of the same scene, while 3D animations are created inside a computer, as virtual scenes, the computer constructing two different viewpoints. It is vital that each eye sees only one of the videos. There are several ways to achieve this, but 3D cinemas normally make use of polarized light (see p. 194).



CAPTURING 3D

To make a live action 3D movie, filmmakers use cameras that capture two images side by side.

SEEING A SCENE

Like all movies, 3D cinema is a sequence of rapidly changing still images, or frames. But 3D cinema uses two images for each frame, projected simultaneously. The light from the two different images is polarized, or twisted, by polarizing filters inside the projector. Each is polarized at a different angle, and must be viewed through 3D glasses with the same polarization. Without viewing glasses, a spectator would just see a blurry picture on the screen.

3D PROJECTORS

Most 3D-ready cinemas have two projectors—one for each video stream. Each frame is produced by a liquid crystal display (see p. 246) then passed through a polarizing filter.

3D GLASSES

Polarizing filters in the glasses block one of the images, but allow the other through. Each eye sees a slightly different viewpoint of the same frame, which the brain perceives as a single, 3D image.

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