CONCEPTUAL EXAMPLE 25–2 **Shutter speed.** To improve the depth of field, you "stop down" your camera lens by two f-stops from $f/4$ to $f/8$. What should you do to the shutter speed to maintain the same exposure?

RESPONSE The amount of light admitted by the lens is proportional to the area of the lens opening. Reducing the lens opening by two f-stops reduces the diameter by a factor of 2, and the area by a factor of 4. To maintain the same exposure, the shutter must be open four times as long. If the shutter speed had been $\frac{1}{500}$ s, you would have to increase it to $\frac{1}{125}$ s.

Picture Sharpness

The sharpness of a picture depends not only on accurate focusing, but also on the graininess of the film, or the number of pixels for a digital camera. Fine-grained films are "slower," meaning they require longer exposures for a given light level.

The quality of the lens strongly affects the image quality, and we discuss lens resolution and diffraction effects in Sections 25–6 and 25–7. The sharpness, or *resolution*, of a lens is often given as so many lines per millimeter, measured by photographing a standard set of parallel lines on fine-grain film. The minimum spacing of distinguishable lines gives the resolution; 50 lines/mm is reasonable, 100 lines/mm is very good.

Pixels and resolution

EXAMPLE 25–3 **Pixels and resolution.** A high-quality 6-MP (6-megapixel) digital camera offers a maximum resolution of 2000×3000 pixels on a 16-mm $\times$ 24-mm CCD sensor. How sharp should the lens be to make use of this resolution?

APPROACH We find the number of pixels per millimeter and require the lens to be at least that good.

SOLUTION We can either take the image height (2000 pixels in 16 mm) or the width (3000 pixels in 24 mm):

$$\frac{3000 \text{ pixels}}{24 \text{ mm}} = 125 \text{ pixels/mm}.$$

We would want the lens to be able to resolve at least 125 lines/mm as well. If it can't, we could use fewer pixels and less memory.

NOTE Increasing lens resolution is a tougher problem today than is squeezing more pixels on a CCD.

When is a photo sharp?

EXAMPLE 25–4 **Blown-up photograph.** An enlarged photograph looks sharp at normal viewing distances if the dots or lines are resolved to about 10 dots/mm. Would an 8×10-inch enlargement of a photo taken by the camera in Example 25–3 seem sharp? To what maximum size could you enlarge this 2000×3000-pixel image?

APPROACH We assume the image is 2000×3000 pixels on a 16×24-mm CCD as in Example 25–3, or 125 pixels/mm. We make an enlarged photo $8 \times 10 \text{ inches} = 20 \text{ cm} \times 25 \text{ cm}$.

SOLUTION The short side of the CCD is $16 \text{ mm} = 1.6 \text{ cm}$ long, and that side of the photograph is 8 inches or 20 cm. Thus the enlargement is by a factor of $20 \text{ cm}/1.6 \text{ cm} = 12.5\times$ (or $25 \text{ cm}/2.4 \text{ cm} \approx 10\times$). To fill the 8×10-inch paper, we assume the enlargement is $12.5\times$. The pixels are thus enlarged $12.5\times$; the pixel count of 125/mm on the CCD becomes 10/mm on the print, so an 8×10-inch print is just about the maximum possible size for a sharp photograph. If you feel 7 dots/mm is good enough, you can enlarge to maybe 11×14 inches.