Astronomy 80 B: Light

Lecture 13: photography, vision

13 May 2003

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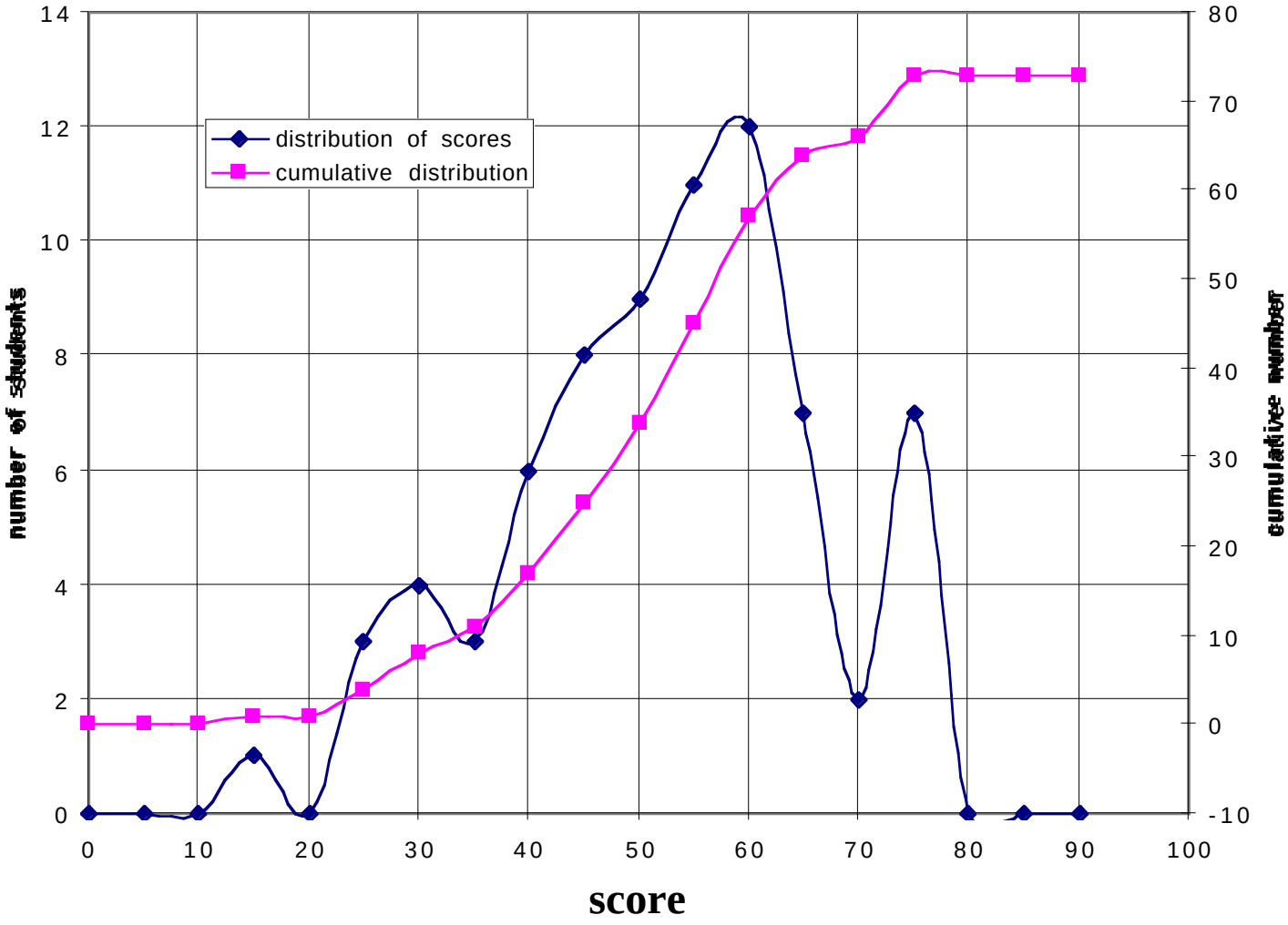
Topics for Today

- Total eclipse of the moon 15 May 2003!!!
- Status of field trip (16 may)
- Statistical summary of Quiz 2
- Status of research/term papers
- Optical illusion
- Pretty picture
- Camera principles
- Introduction to vision

Total eclipse of moon

- **Start of partial eclipse (enter penumbra) 19:03**
- **Total eclipse starts (enter umbra) 20:14**
- **Sunset 20:15**
- **Mid-eclipse 20:40**
- **Total eclipse ends (exit umbra) 21:07**
- **Partial eclipse ends (exit penumbra) 22:18**

quiz 2


distribution of scores
cumulative distribution
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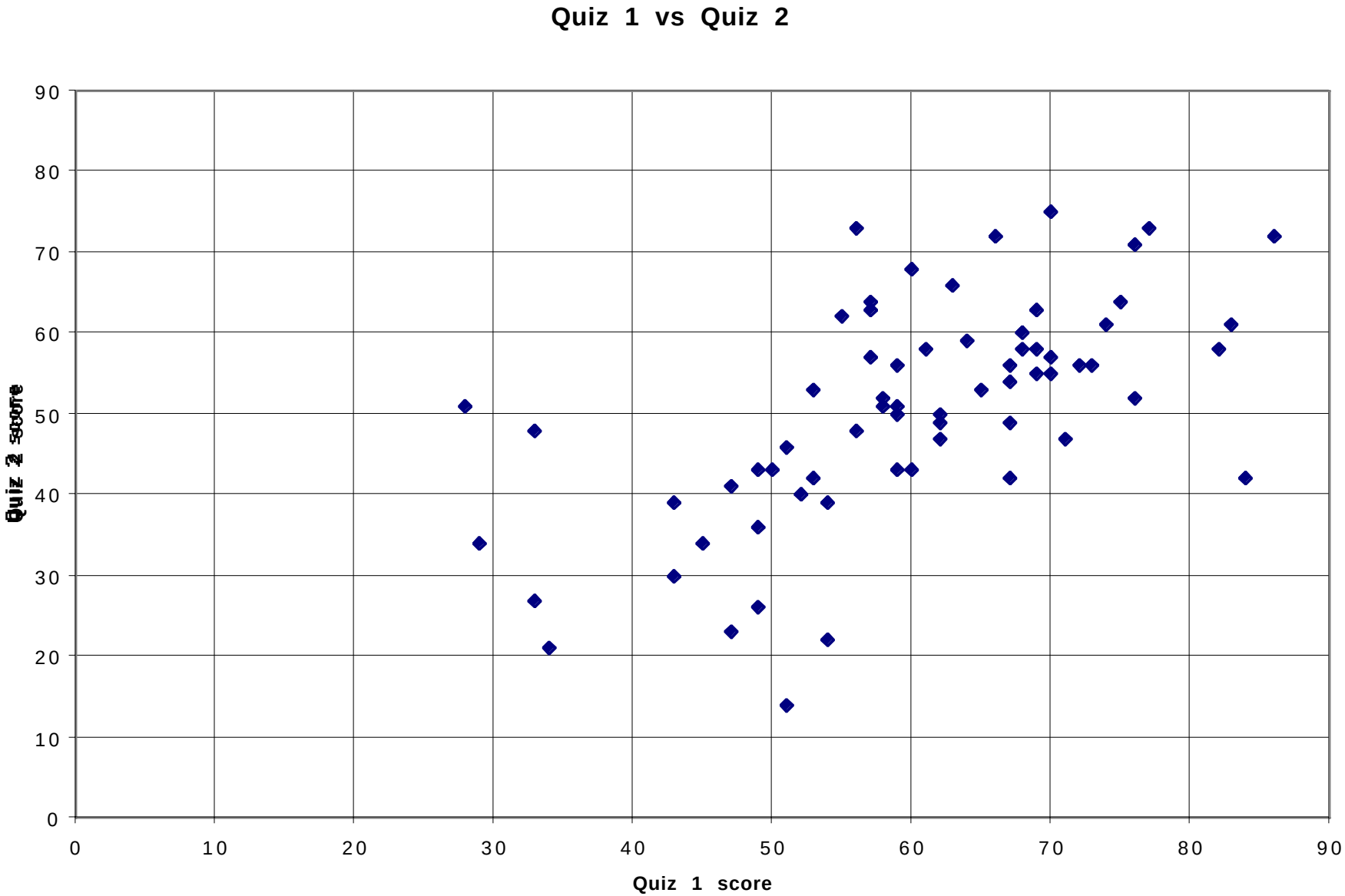
Quiz 1 vs Quiz 2
Quiz 2 score
Quiz 1 score
0
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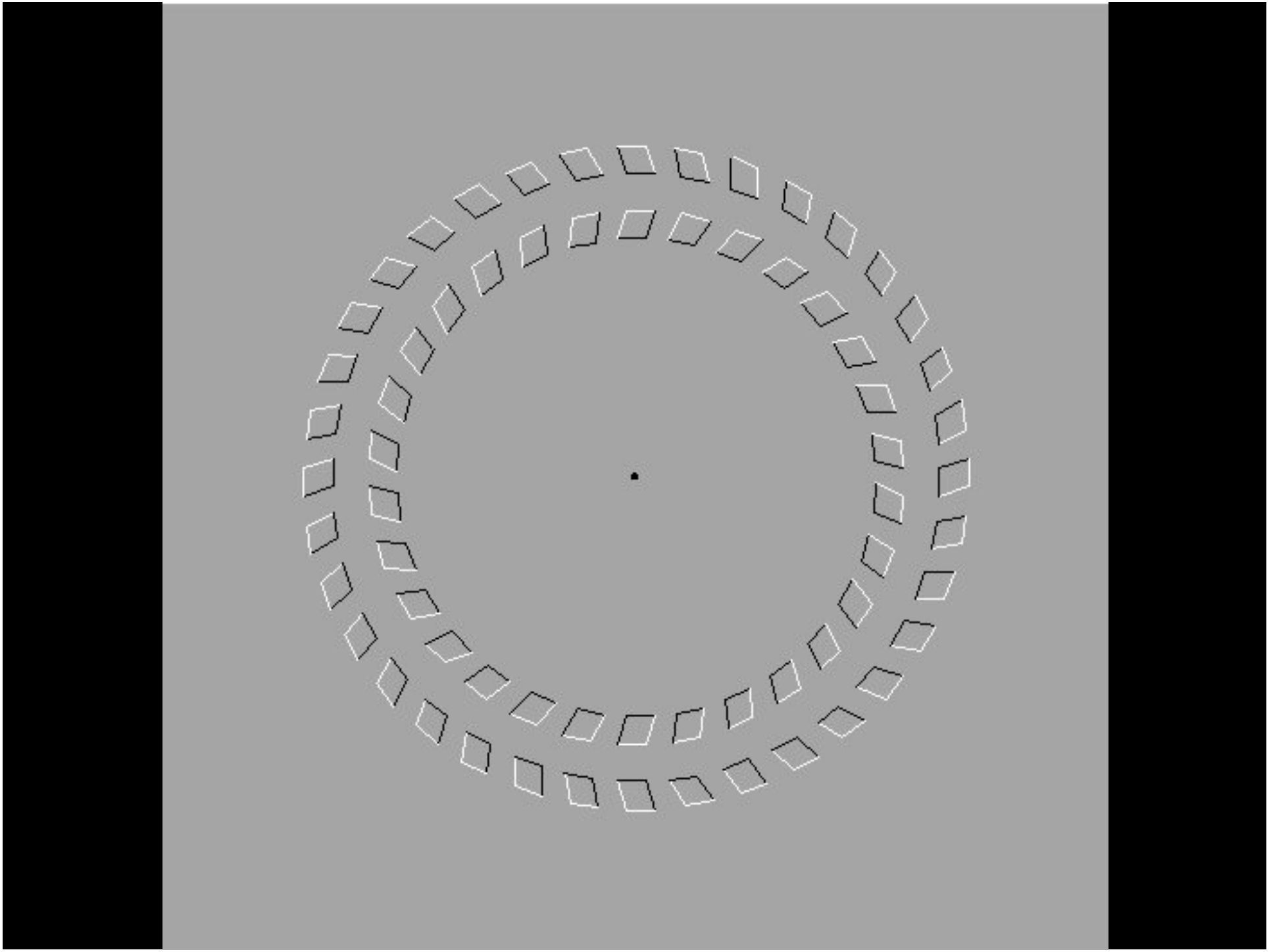
60
70
80
90

Research papers

- **I need your subject and I need to approve it**
- **So far, 20 paper subjects have been approved!**
- **Paper must include observations or actual measurements of experimental tests**
- **Process**
  - Select subject
  - Get subject approved
  - Make outline of your planned paper with desired measurements
  - Write draft of paper, emphasizing the data
  - Bring draft to class on 15may, for review by class (we will break up into small groups and pass around drafts for comment by students)



Zoom lens

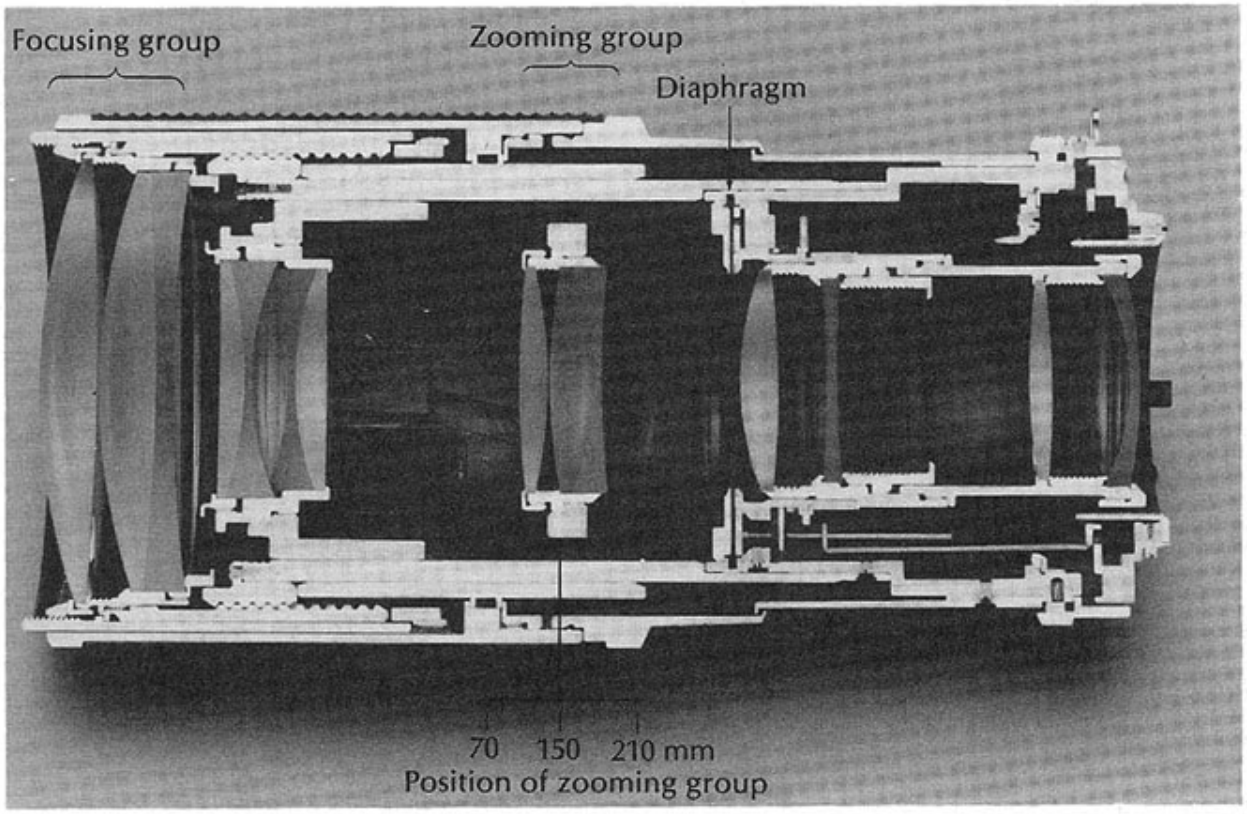


FIGURE 4.19

A zoom lens (Vivitar Series 1 Macro) at $f = 70$ mm and $f = 210$ mm. The lens elements move and also change their spacing in just such a way as to keep the image on the film plane.

- **Wide angle photograph of a convex mirror**

FIGURE 4.20

Wide-angle photograph taken in a convex mirror. Compare with Figure 3.9 and note that the place of Escher's head is here taken by the camera that took the picture. See also Figure 3.5b. Note the circles of confusion resulting from light points in the (out-of-focus) background.

- 1/1000
- 1/500
- 1/250
- 1/125
- 1/60
- 1/30 s

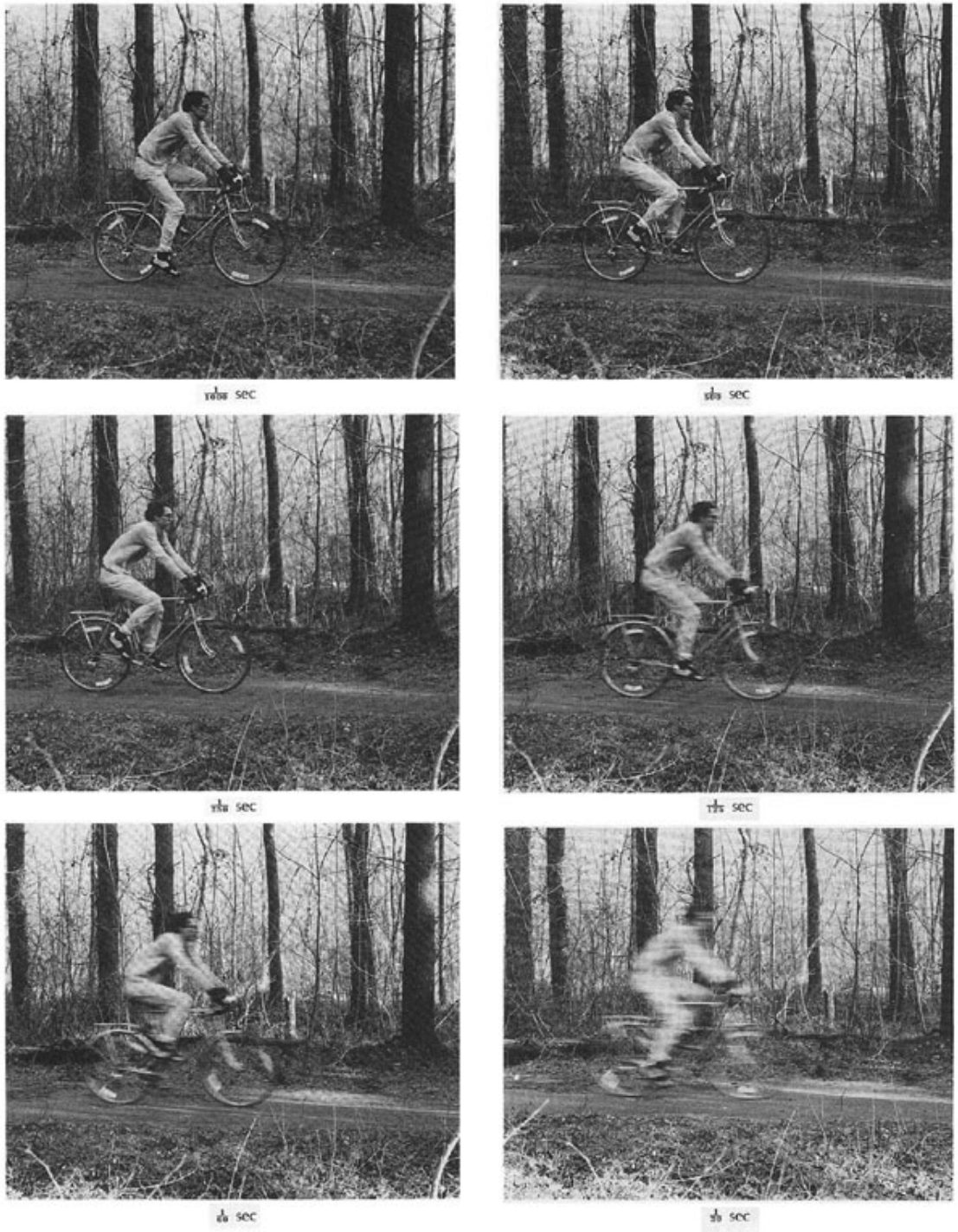


FIGURE 4.21

The action-stopping power of a shutter. The shutter speeds are given below each photo. (Also see stars in Fig. 2.41b.)

- **1/15 second**
- **1/8**
- **1/4**
- **1/2**

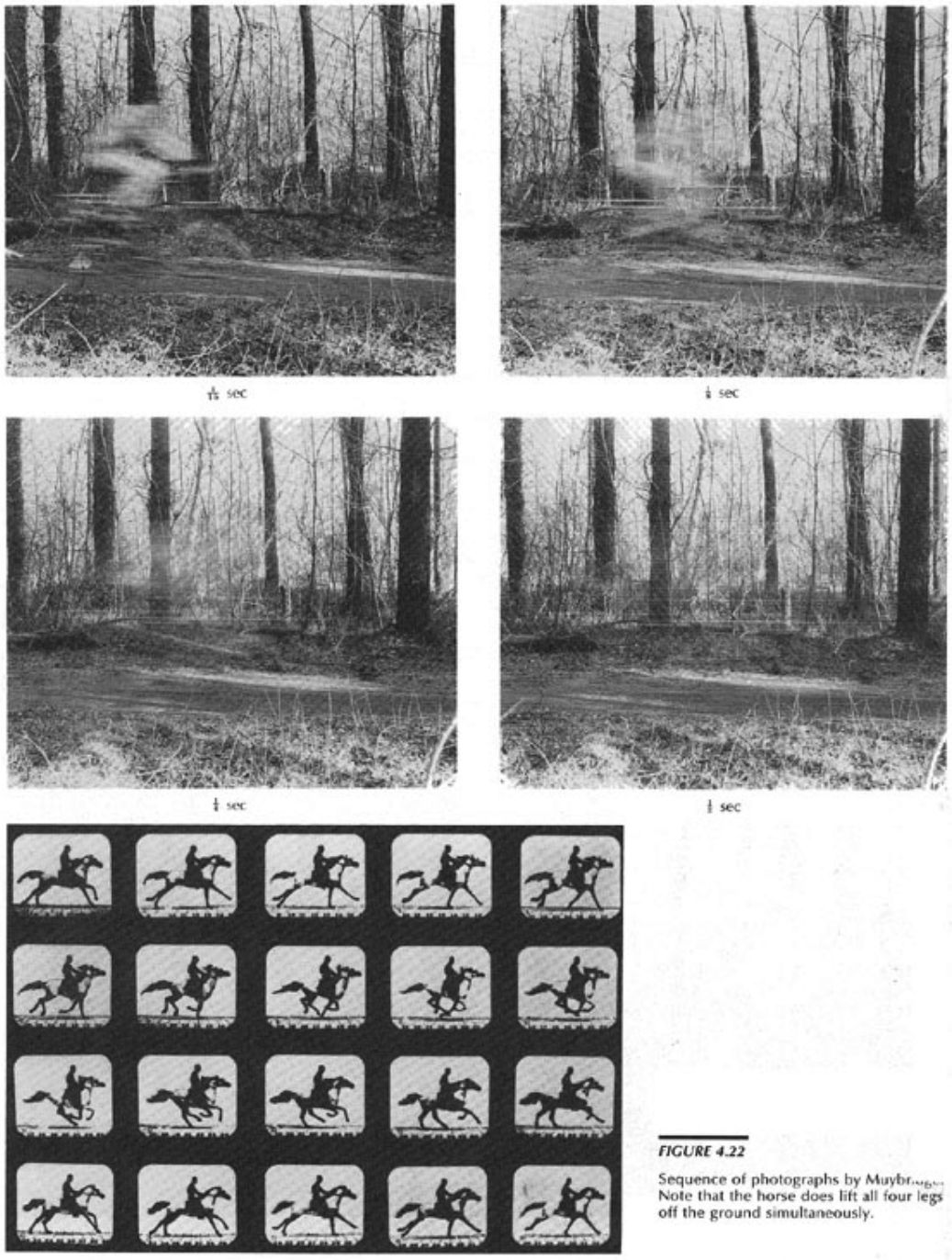


FIGURE 4.22

Sequence of photographs by Muybr... Note that the horse does lift all four legs off the ground simultaneously.

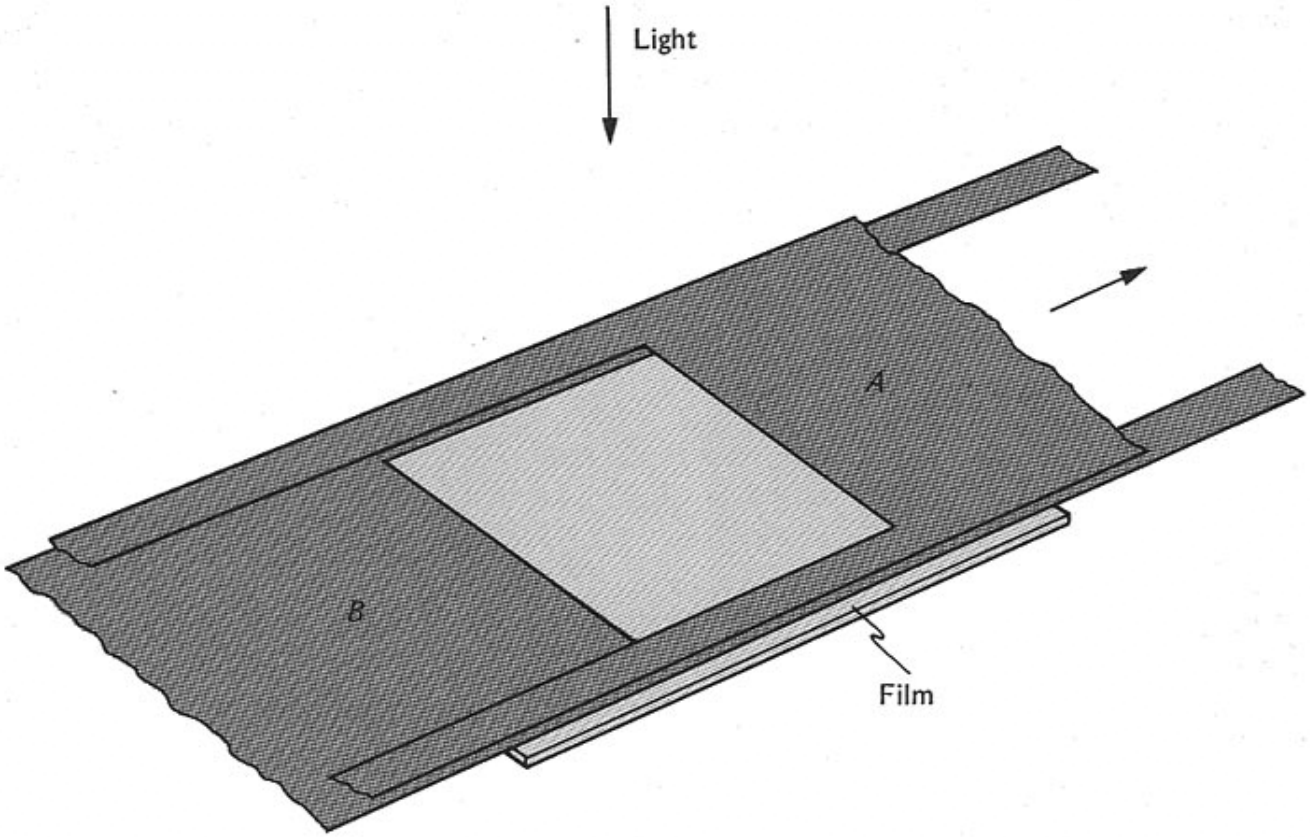


FIGURE 4.23

The principle of the focal-plane shutter. The two parts of the curtain always move across the film at the same speed, but part *B* is delayed by different amounts behind part *A* for different exposure times, creating a moving slot of different widths.

Effect of vertical motion shutter

- **Photographing a high speed object, along with shutter motion, can distort the image**

FIGURE 4.24

Photograph illustrating the distortion of a rapidly moving car due to a focal-plane shutter, here moving vertically. Modern focal-plane shutters move much faster, so the distortion is usually negligible, except for extremely rapidly changing scenes such as in Figure 4.26.

High speed photo

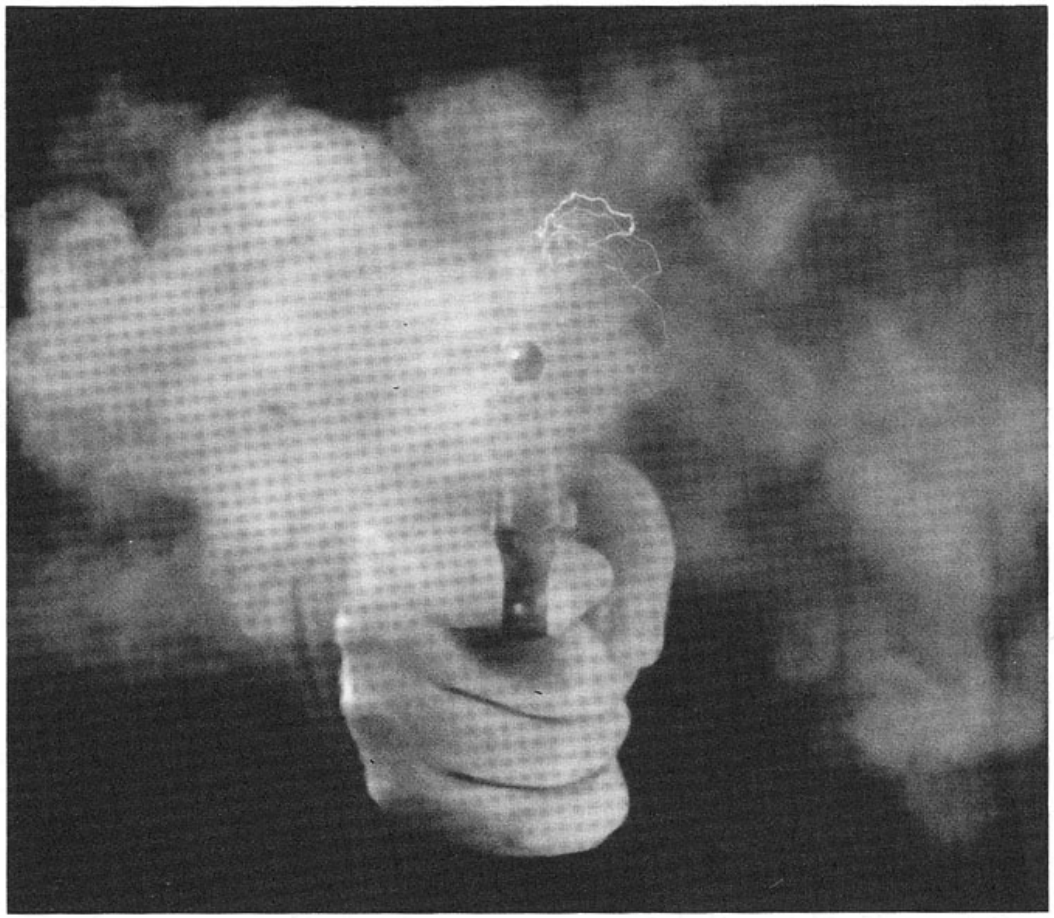


FIGURE 4.25

Photograph of a bullet in flight, exposed for 10 μsec.

Camera shutter and video scan interaction

- **Video horizontal scan lines run from top to bottomand take 1/60 second to complete screen**
  - The TV electron beam moves horizontally across the TV screen phosphors and makes them glow- give off light

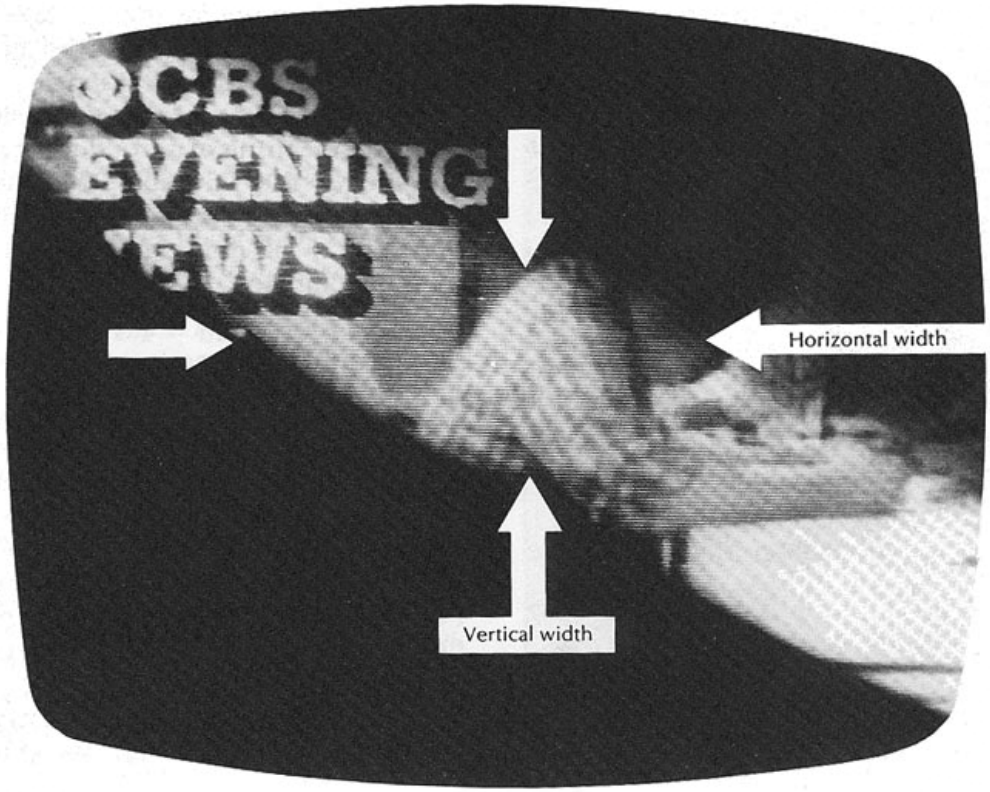


FIGURE 4.26

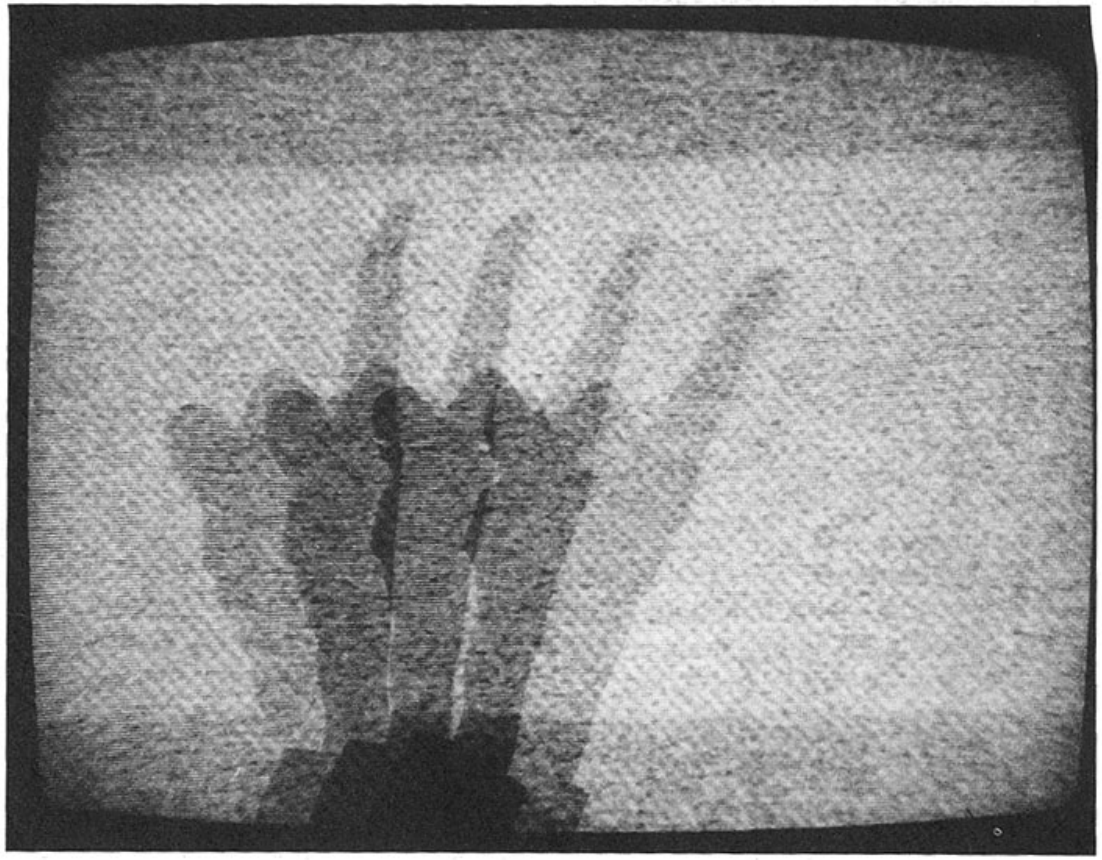
Photograph of a TV screen, taken using a focal plane shutter at $\frac{1}{250}$ sec.

Video scan pattern, moving hand, and camera

- **Here the video scan pattern repeated four times during the camera exposure time of 1/15 second, and the hand was moving**

FIGURE 4.27

Photograph of a moving hand in front of a TV screen taken at $\frac{1}{15}$ sec.



Stops

- **Variable stop**
  - Cameras have devices inside them to adjust the size of the stop, either manually or automatically
  - This controls the amount of light
  - This also influences the f ratio, hence the depth of field

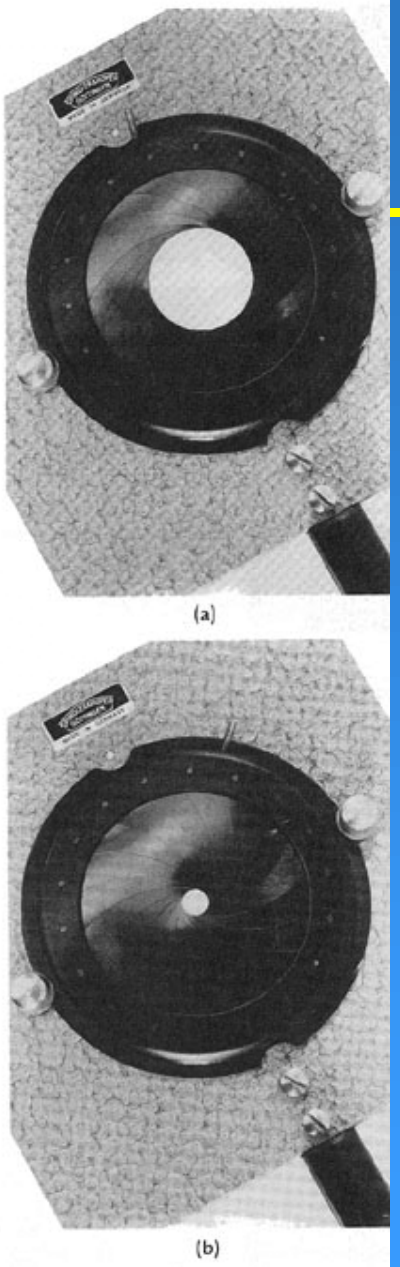
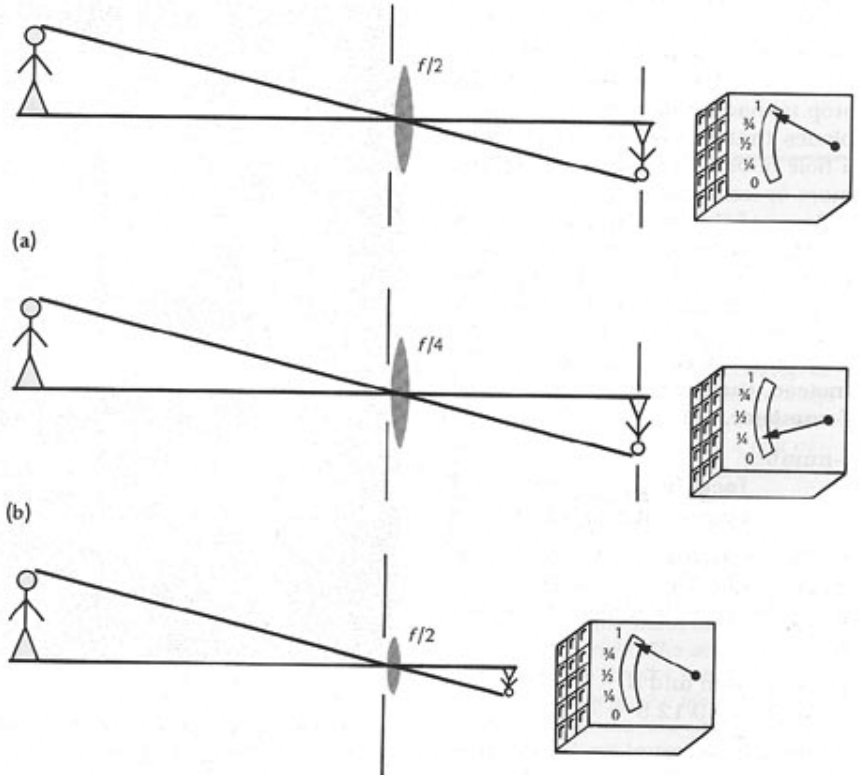


FIGURE 4.28
Photographs of a variable stop.

- **F- numbers and light intensity**
  - F- number is the focal length divided by the clear aperture
  - Also noted as f# or f/#
  - For a given focal length, a higher f# allows less light onto the detector (smaller aperture)
  - For a given aperture, longer focal length spreads the light out over a larger detector area (bigger image)

FIGURE 4.29

f-numbers and relative light intensity on the film. **(a)** A long focal length lens has an aperture set to f/2. The meter shows the relative light intensity on the film plane. **(b)** The lens of **(a)** is stopped down to f/4—the diameter of the aperture is one half that shown in **(a)**. Because one fourth the amount of light can now get through the lens (and the image remains the same size), the light intensity on the film plane is one fourth that in part **(a)**, as shown by the meter. **(c)** A short focal length lens produces a small image. The aperture here is the same as in **(b)** and thus the same light energy as in **(b)** strikes the film. This light, however, is concentrated over an image one fourth the area of that in **(b)**, and thus the light intensity on the film plane is four times that in **(b)**. The f-number for this short focal length lens is the same as in part **(a)**, and hence the light intensity on the film plane is the same as in **(a)**.



- **Effect of the stop size on the depth of field**
  - Stop down camera, get greater depth of field
  - Larger f number means stopped down lens

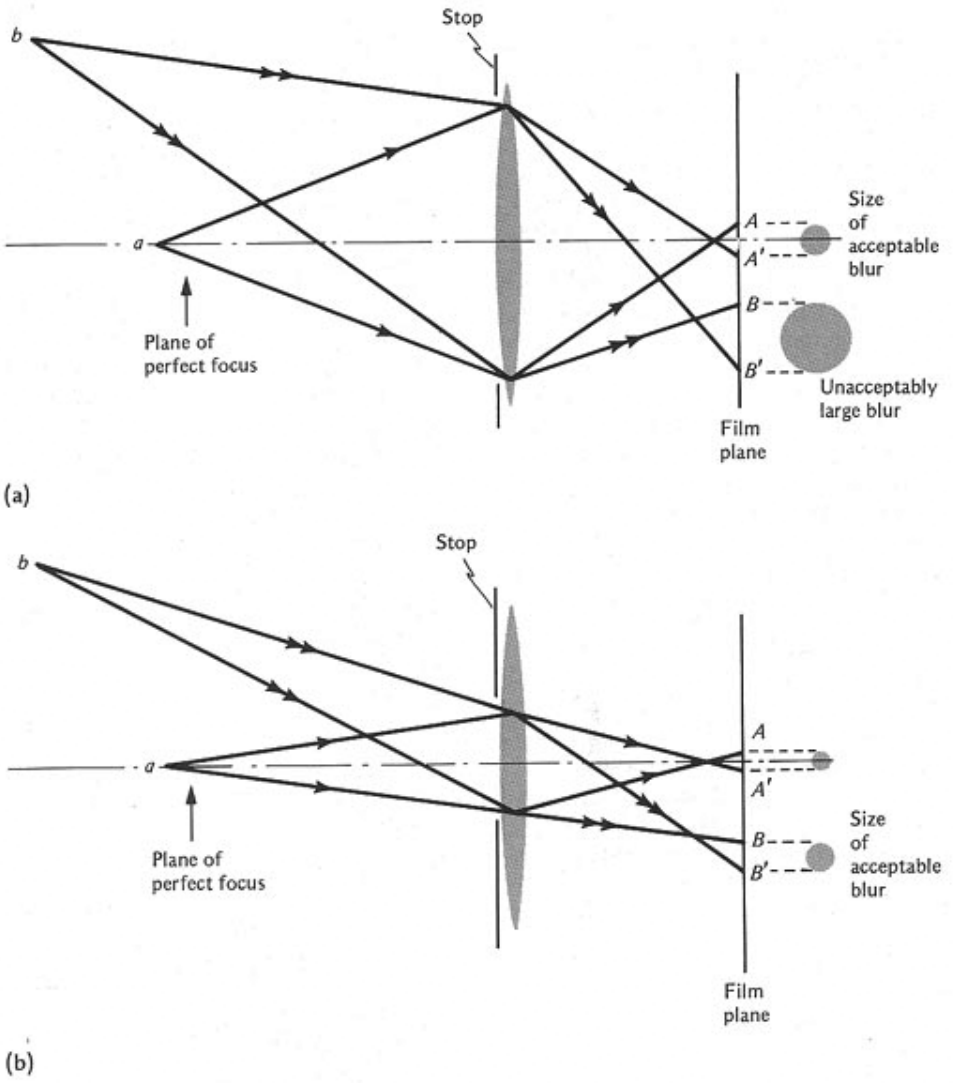


FIGURE 4.30

The effect of stop size on the depth of field. **(a)** The circle of confusion of object *a* has diameter *AA′*, smaller than the acceptable blur size; *a* is in focus. Object *b*, however, has an unacceptably large blur size *(BB′); b* is out of focus. **(b)** The smaller stop reduces the size of each circle of confusion. Now both *a* and *b* are acceptably in focus.

- **Examples of the effect of f number on depth of field**
  - F/16
  - F/11
  - F/8
  - F/5.6
  - F/4
  - F2.8
  - F/2

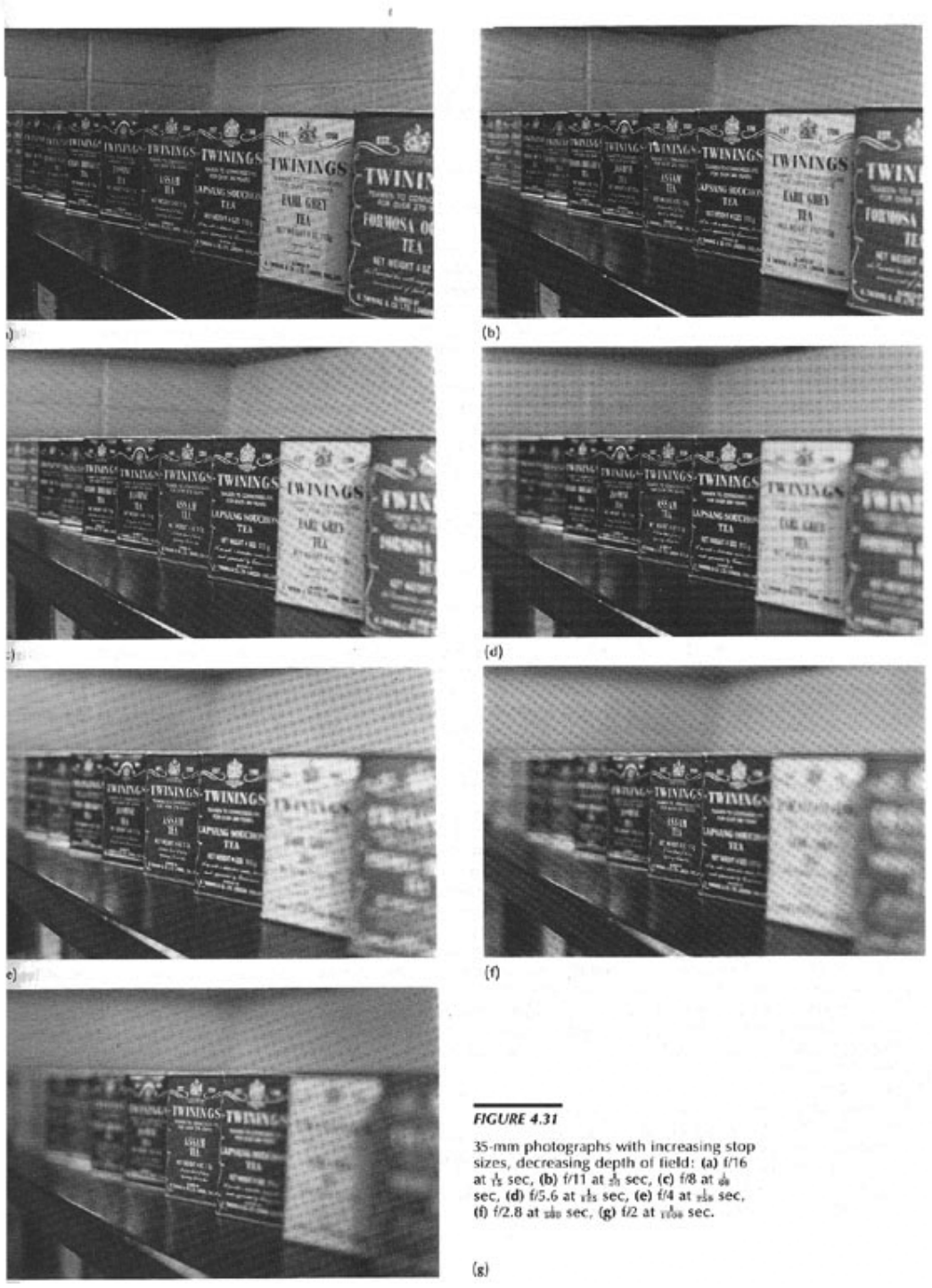


FIGURE 4.31

35-mm photographs with increasing stop sizes, decreasing depth of field: **(a)** f/16 at $\frac{1}{15}$ sec, **(b)** f/11 at $\frac{1}{30}$ sec, **(c)** f/8 at $\frac{1}{60}$ sec, **(d)** f/5.6 at $\frac{1}{125}$ sec, **(e)** f/4 at $\frac{1}{250}$ sec, **(f)** f/2.8 at $\frac{1}{500}$ sec, **(g)** f/2 at $\frac{1}{1000}$ sec.

Shallow depth of field

FIGURE 4.32

Here a shallow depth of field is used to blur an undesirable foreground. The out-of-focus wires of the cage are almost invisible, except in the upper left corner.

Camera Types

- **Cameras can be classified by:**
  - size of image: the film sizes commonly used

35 mm film	actually 24mm x 36 mm
110 film	actually 8mm x 12 mm
120 roll film	actually 60mm x 60 mm
220 film	same, roll is twice as long
large format	4" x 5" or larger

  - Resolution of light detector
    - 35 mm film has roughly 4 million resolution elements
    - digital cameras have resolutions measured in pixels
    - a pixel is a picture element~a resolution element
    - typical formats: (recording is usually JPG)

      640 x 480 = 0.31 mega pixels

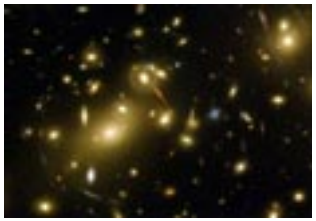
      1024 x 768 = 0.79 mega pixels
    - Best home cameras now ~ 5 mega pixels
  - the kind of viewing system
  - the kind of focusing mechanism

The Light Sensor

- **The camera focuses the object onto the image plane**
- **The image plane is where the light sensor should be placed**
- **Typical light sensors (or detectors)**
  - Photographic film sense elements/grains ~ 15 microns
  - CCD's (silicon-charge coupled device) pixels ~ 5 microns
  - CMOS (silicon - complementary metal oxide)

Digital Cameras

- **Digital cameras have the same optics as film cameras**
  - The light sensor is usually significantly smaller than film for the same resolution, and this allows the optics to be smaller, and the camera to be smaller
  - The light sensor is composed of discrete picture elements, called pixels, that form an array of pixels (usually a CCD sensor)
- **Each pixel basically detects the number of photons that hit it, independent of color**
  - The signal is the number of light generated electrons in that pixel
  - This is measured and digitized by an analog to digital converter (ADC)
  - The digital result is stored in computer memory in the camera
- **Color is established by placing filters in front of each pixel**
  - Interpolation schemes are needed to make “color” for each pixel

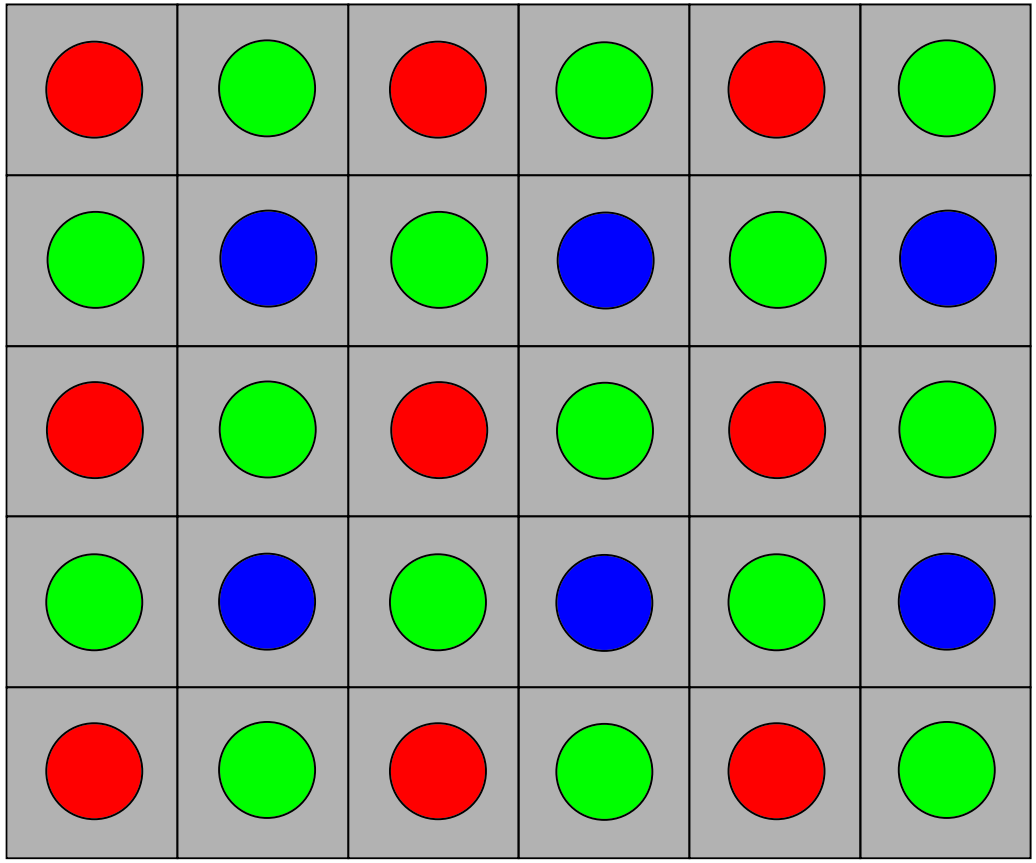


Digital Cameras-color filters and pattern

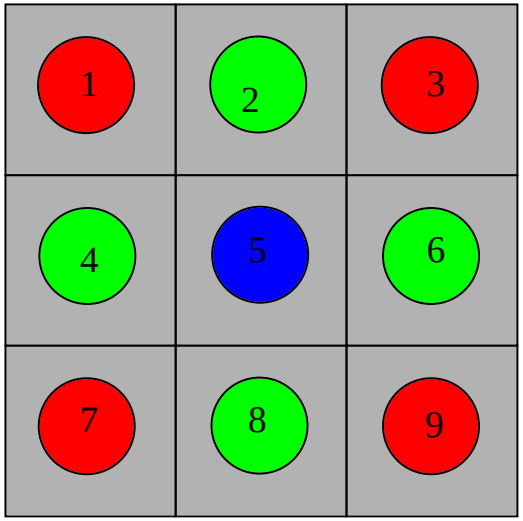
5 x 6 array of pixels and RGB color filters above them

Only light passing through filter gets to detector (so some is lost)

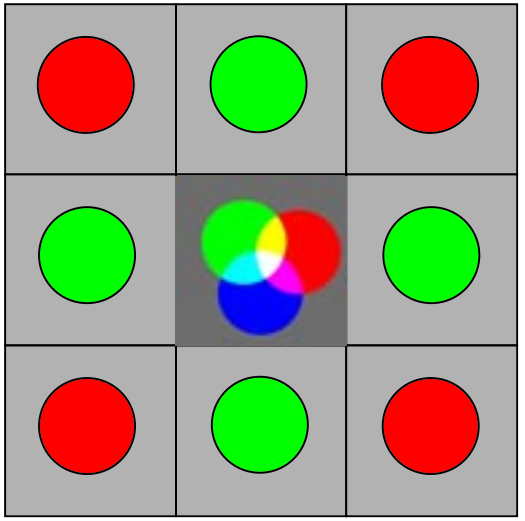
This pattern is called the Bayer pattern, named after Kodak engineer who developed it

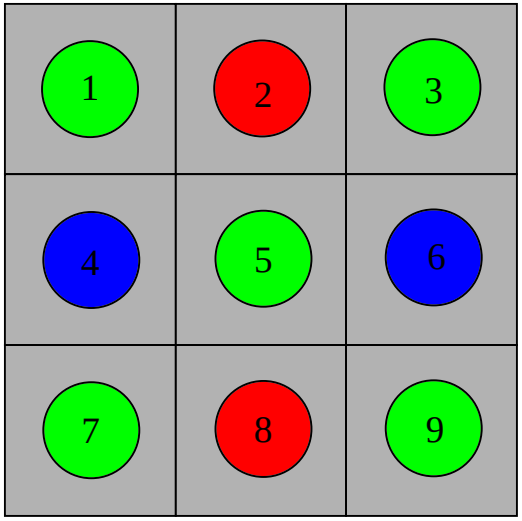


Digital Cameras: interpolating color to assign a color strength for each pixel for each of RBG



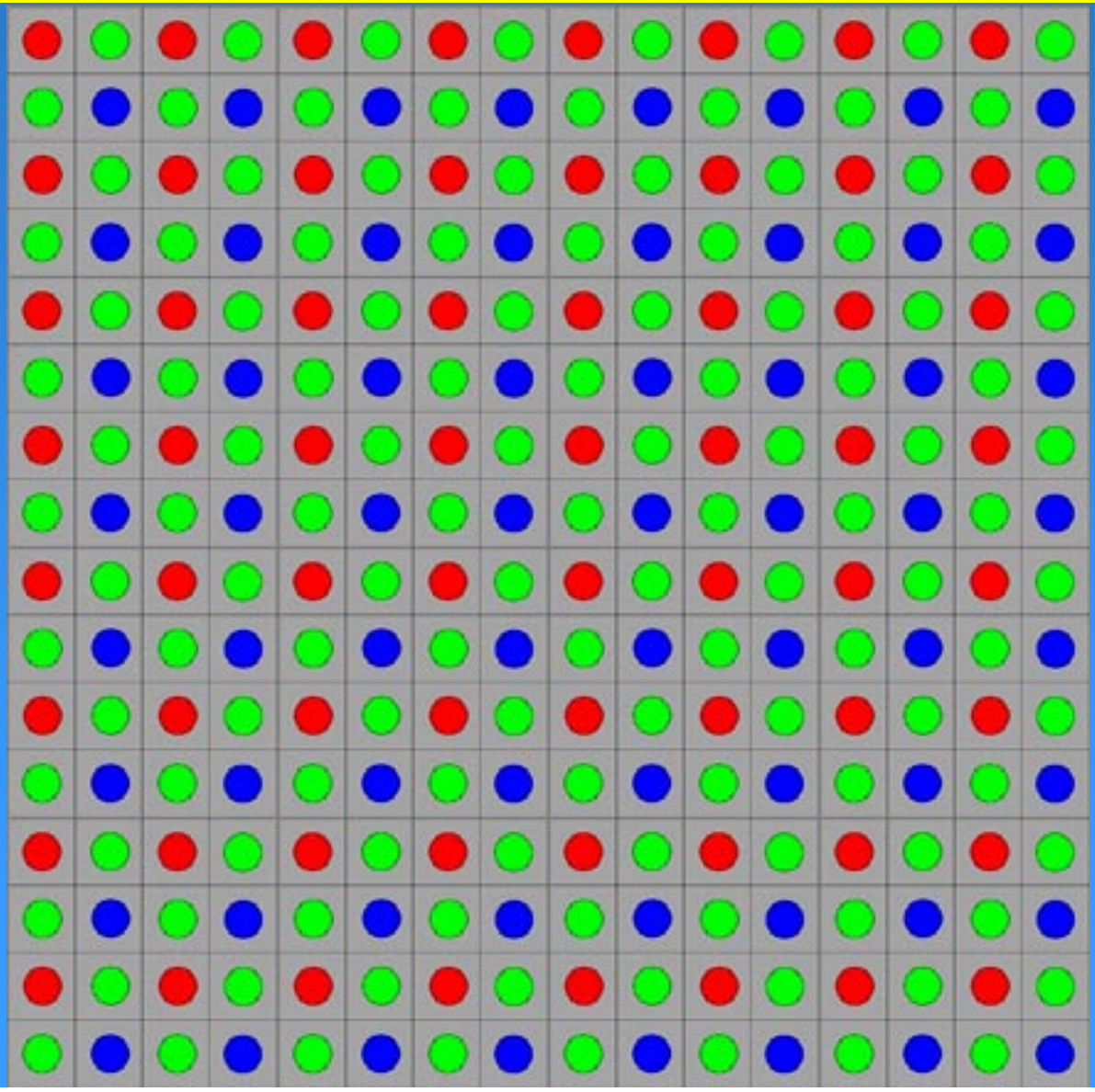
For cell 5
Red = average of 1,3,7,9
Green = average of 2,4,6,8
Blue = 5



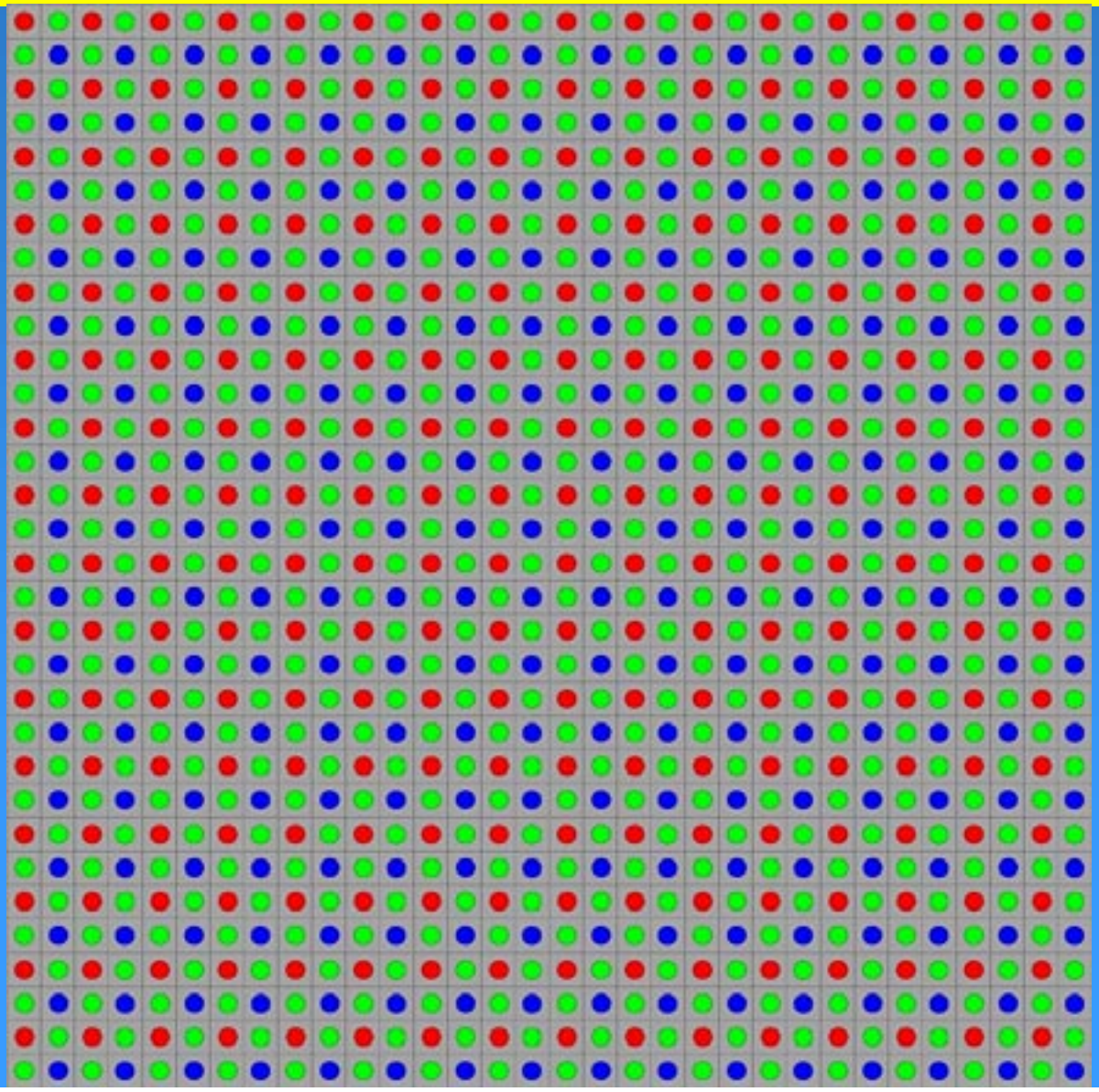


For cell 5
Red = average of 2,8
Green = 5 or average of 1,3,7,9 averaged with 5?
Blue = average of 4,6

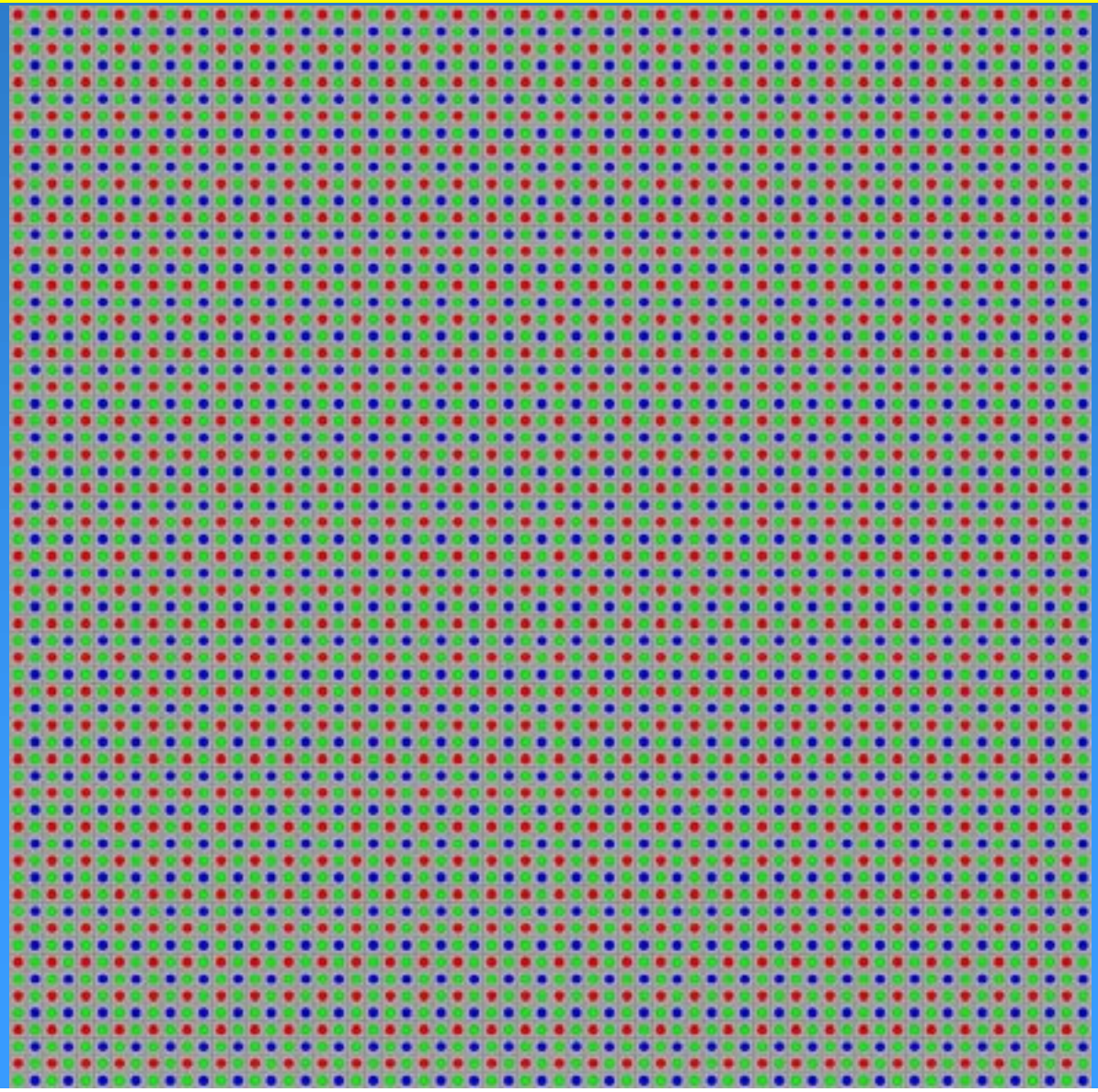
16 x 16 pixel array



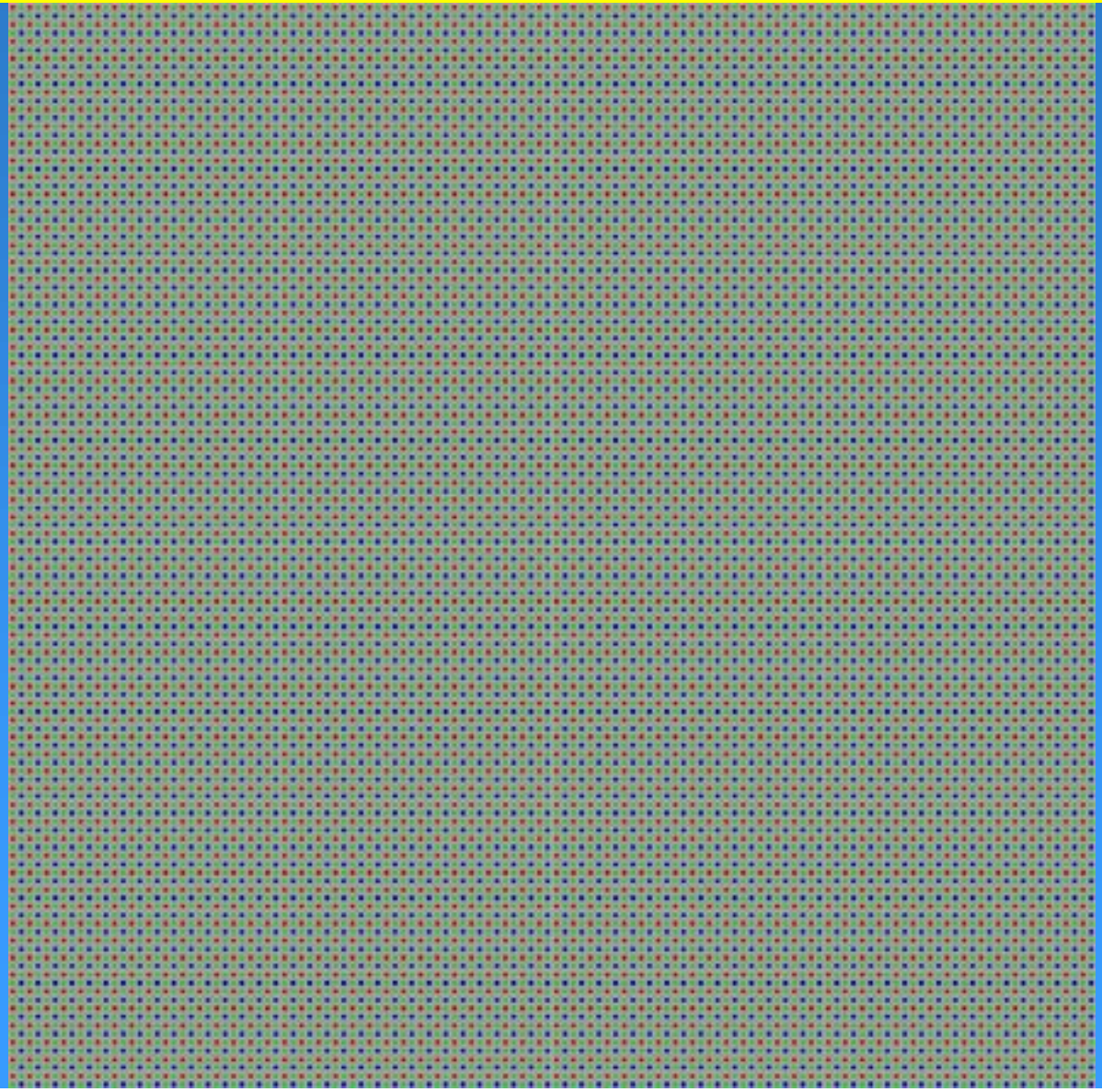
32 x 32 pixel array

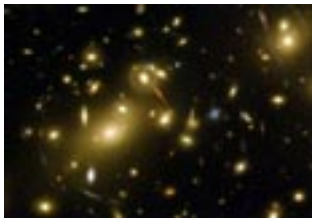


64 x 64 pixel array



128 x 128 pixel array

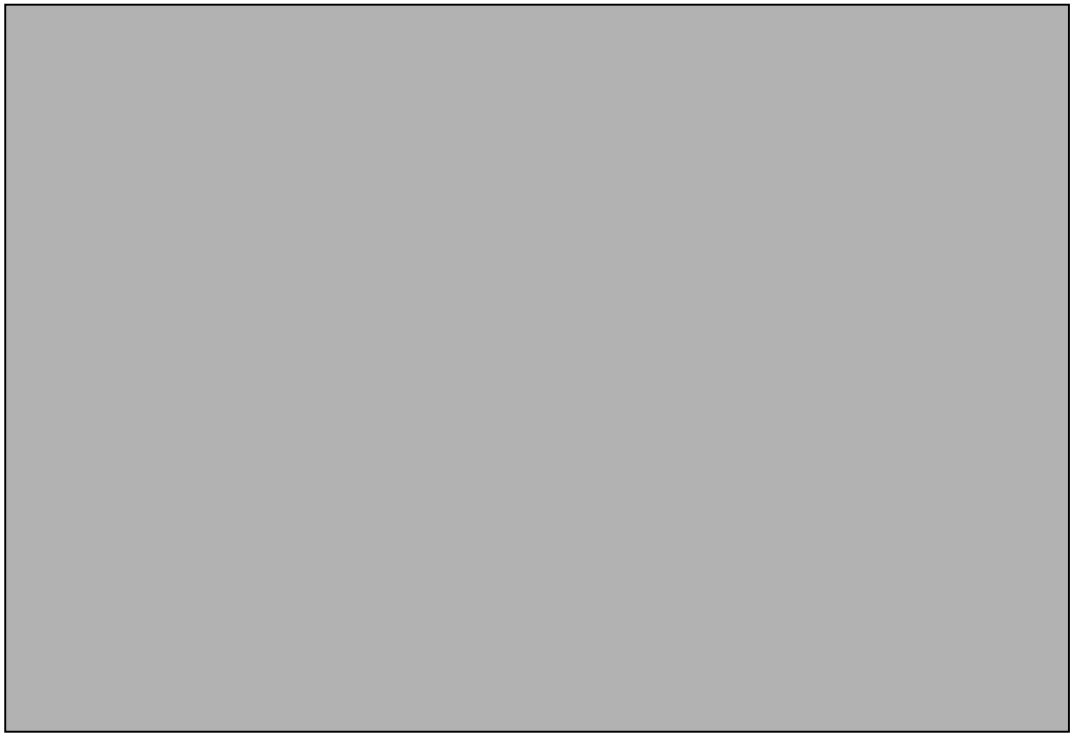




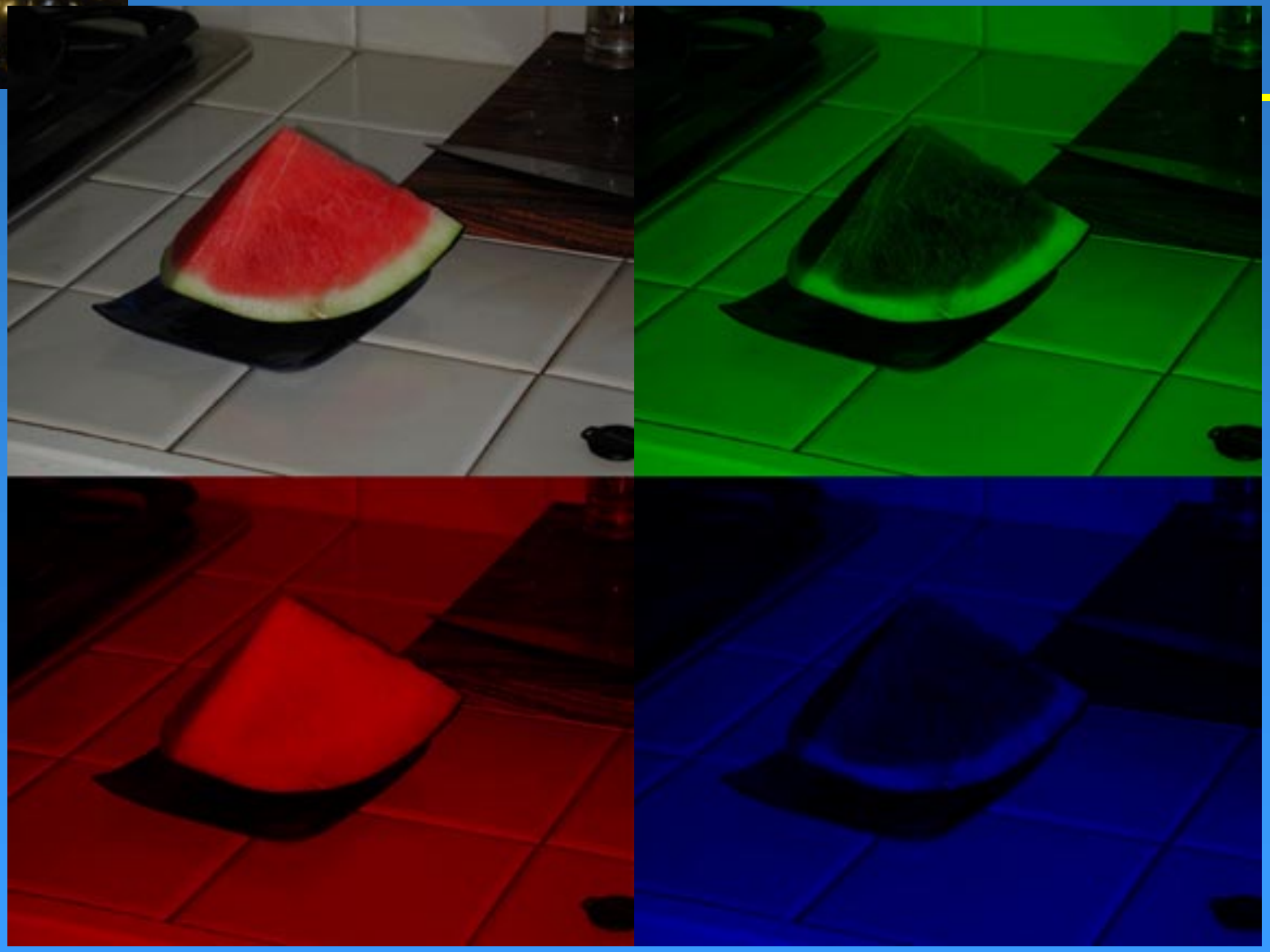
Digital Cameras

2000 x 3000 pixel array

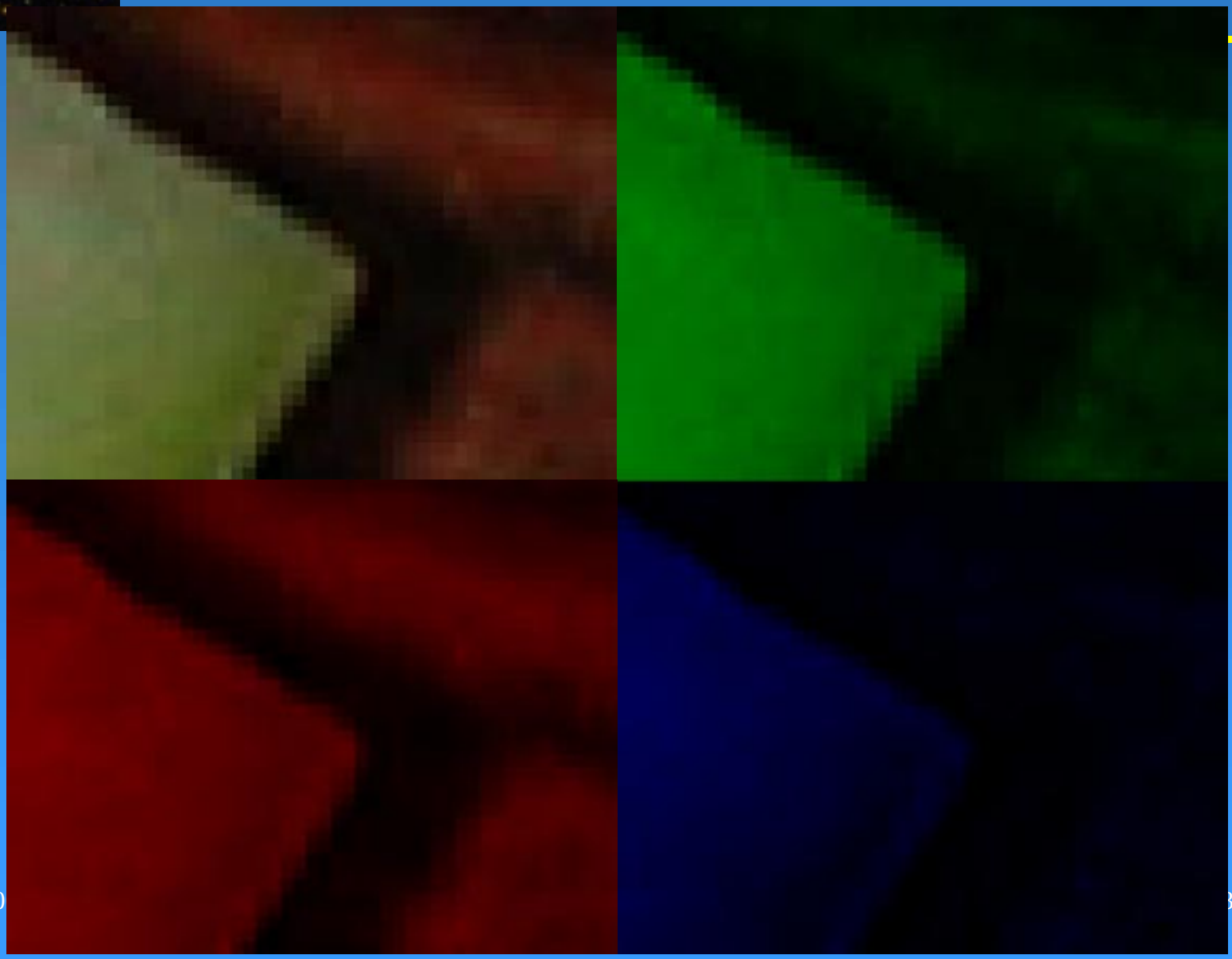
6 Mega pixel camera



Color picture and its 3 color components RGB



Blow up of picture showing pixels and its 3 color components



Further blowup showing pixels

Film

- **Film as a light sensor is still very popular and is a mature and inexpensive technology**
  - Its days are probably numbered (or at least its years), as digital devices become more available and capable
- **Film works by photochemistry**
  - Certain substances/molecules are altered by exposure to light
  - These changes can be made permanent by careful planned chemical reactions
  - Film is exposed to light
  - Exposed film is developed to make the effects of exposure permanent
  - The density of developed film (degree of opacity to light) is generally a non-linear function of the amount of exposure
  - Details in book

35 mm camera focal length vs angle of view

TABLE 4.1 Focal length and angle of view for 35-mm cameras

Focal length of camera lens	*Wide angle*			*Normal*	*Telephoto*		
	17 mm	*28 mm*	*35 mm*	*50 mm*	*85 mm*	*135 mm*	*300 mm*
Diagonal angle	104°	75°	63°	47°	29°	18°	8.2°
Horizontal angle	93°	65°	54°	40°	24°	15°	6.9°
Vertical angle	70°	46°	38°	27°	16°	10°	4.6°

Standard sequence of f-numbers

TABLE 4.3 Standard sequence of f-numbers

. . . 0.7, 1, 1.4, 2, 2.8, 4, 5.6, 8, 11, 16, 22, 32, . . .

← Larger aperture — More light

Smaller aperture → — Less light

- **These steps are each factors of 2 in intensity (amount of light entering the camera per unit time)**
- **F/0.7 the largest opening (more light)**
- **F/32 the smallest opening (least light)**

Relationship between f-number and exposure time

TABLE 4.4 Equivalent settings

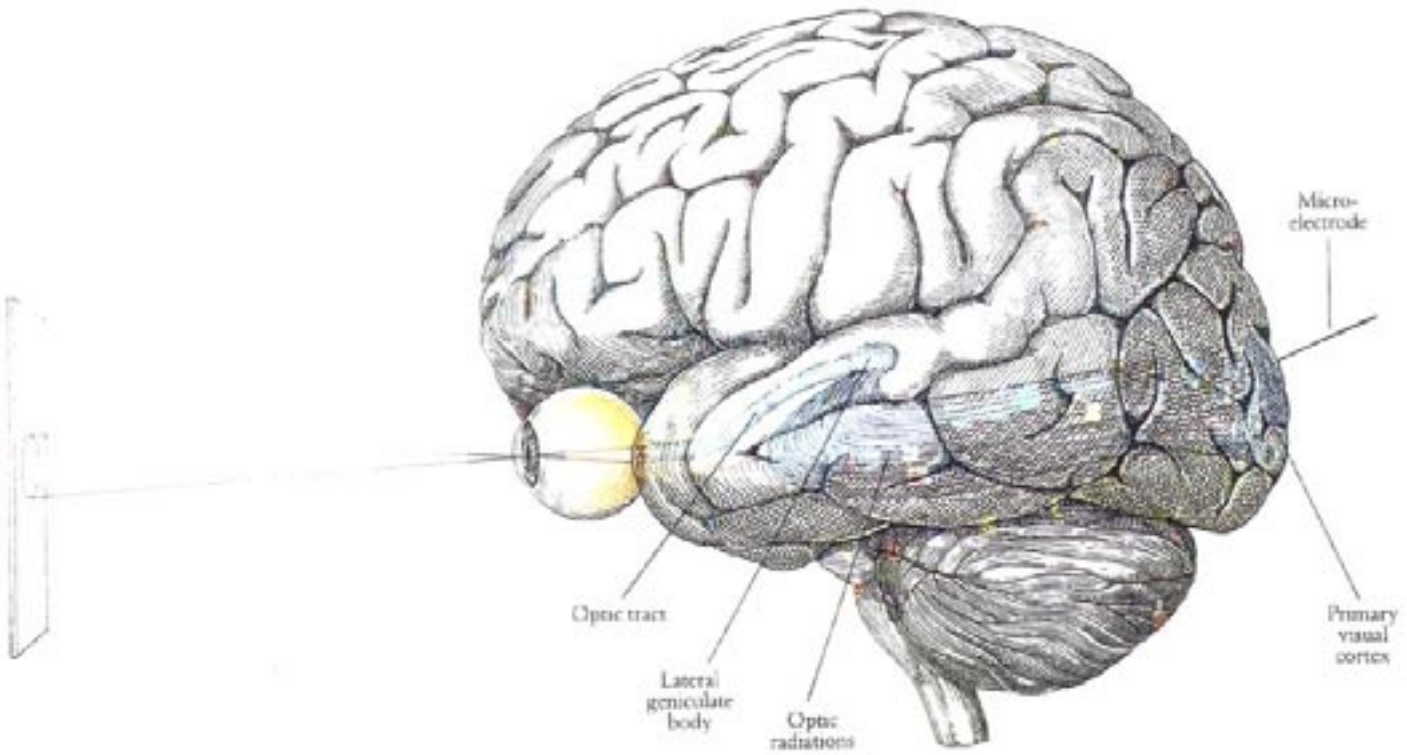
Exposure time (seconds)	$\frac{1}{1000}$	$\frac{1}{500}$	$\frac{1}{250}$	$\frac{1}{120}$	$\frac{1}{60}$	$\frac{1}{30}$	$\frac{1}{15}$
f-number	f/2.8	f/4	f/5.6	f/8	f/11	f/16	f/22

- **Above table shows exposure-f# pairs that allow the same amount of light onto the detector**

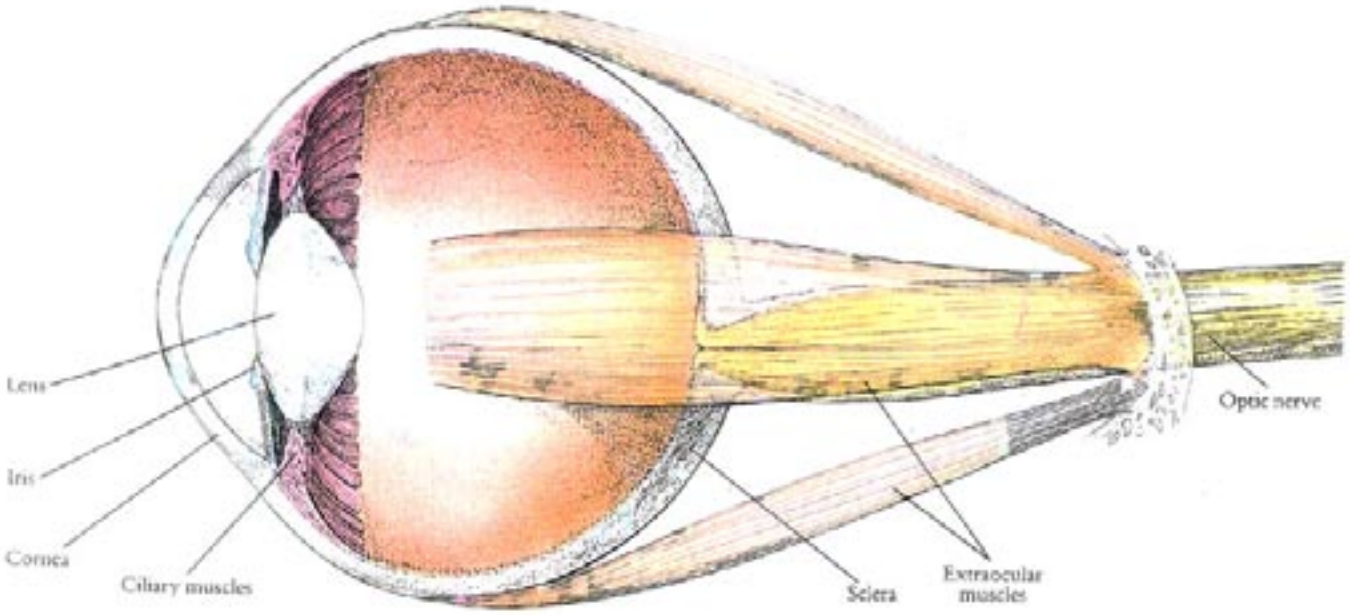
Vision

- **Many animals have light sensors**
- **These vision systems vary greatly in complexity**
  - Angular resolution
  - Number of light sensors
  - Wavelength range of sensors
  - Number of kinds of wavelength sensors
  - Wavelength sensitivitites of sensors (color vision)
- **Human vision is extremely sophisticated**
- **Beyond the optics, the processing of the information is complex and only partially understood**

Eye and brain



Eye system


Lens
Iris
Cornea
Ciliary muscles
Sclera
Extraocular muscles
Optic nerve