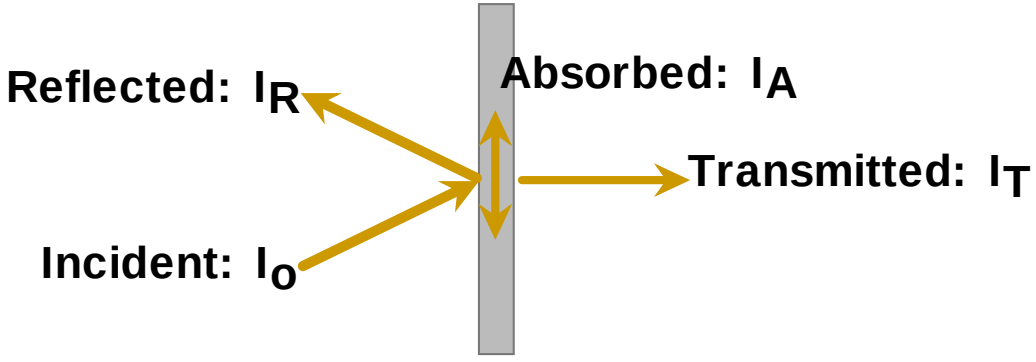
CHAPTER 21:
OPTICAL PROPERTIES

ISSUES TO ADDRESS...

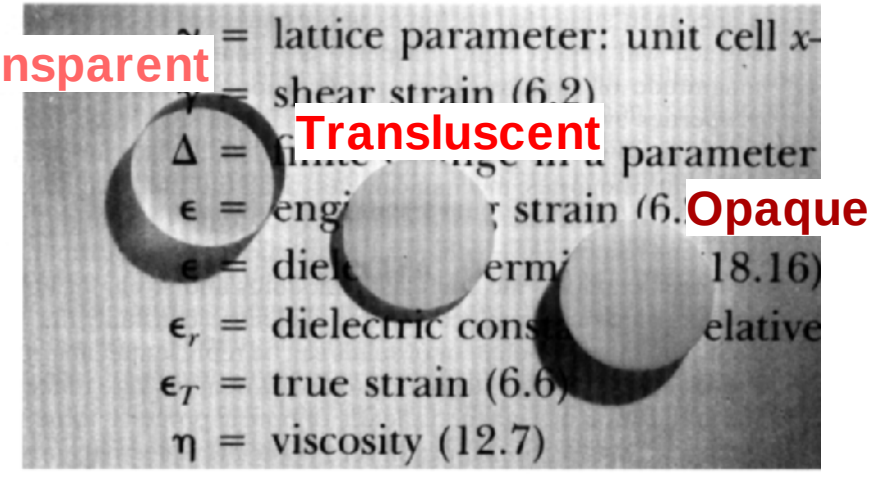
- What happens when light shines on a material?
- Why do materials have characteristic colors?
- Why are some materials transparent and other not?
- Optical applications:
  --luminescence
  --photoconductivity
  --solar cell
  --optical communications fibers

LIGHT INTERACTION WITH SOLIDS

- **Incident light is either reflected, absorbed, or transmitted:** $I_o = I_T + I_A + I_R$



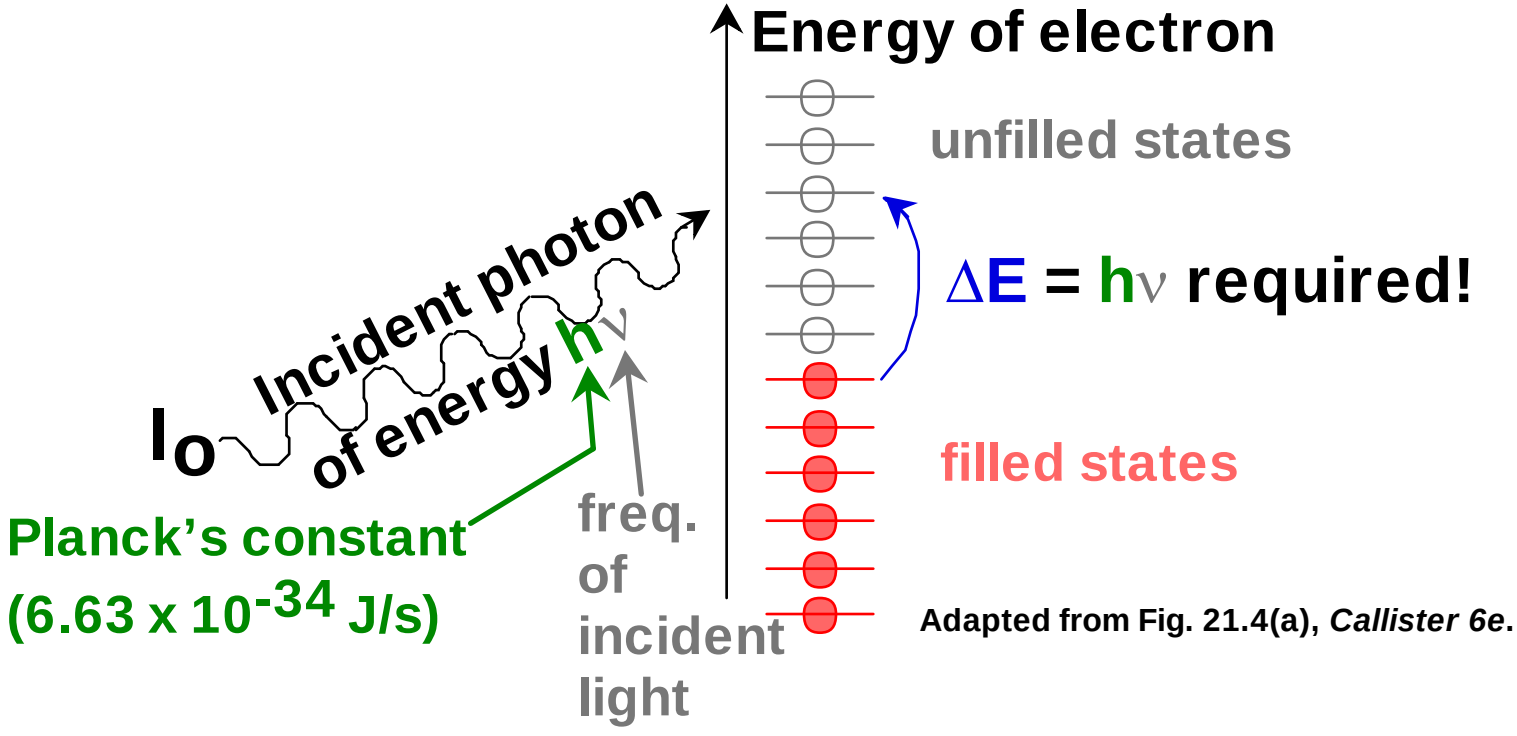
- **Optical classification of materials:**



Adapted from Fig. 21.10, *Callister 6e*. (Fig. 21.10 is by J. Telford, with specimen preparation by P.A. Lessing.)

OPTICAL PROPERTIES OF METALS: ABSORPTION

- **Absorption** of photons by electron transition:

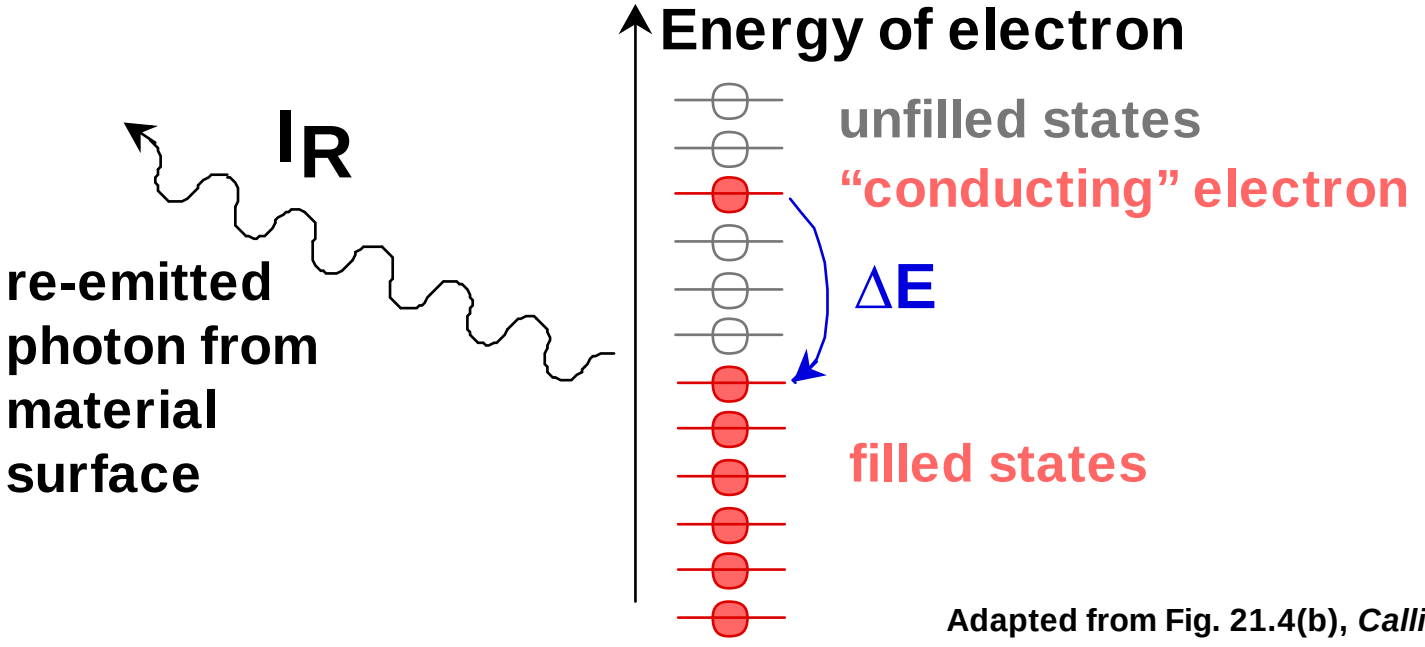


Adapted from Fig. 21.4(a), *Callister 6e*.

- Metals have a fine succession of energy states.
- Near-surface electrons absorb visible light.

OPTICAL PROPERTIES OF METALS: REFLECTION

- **Electron transition** emits a photon.

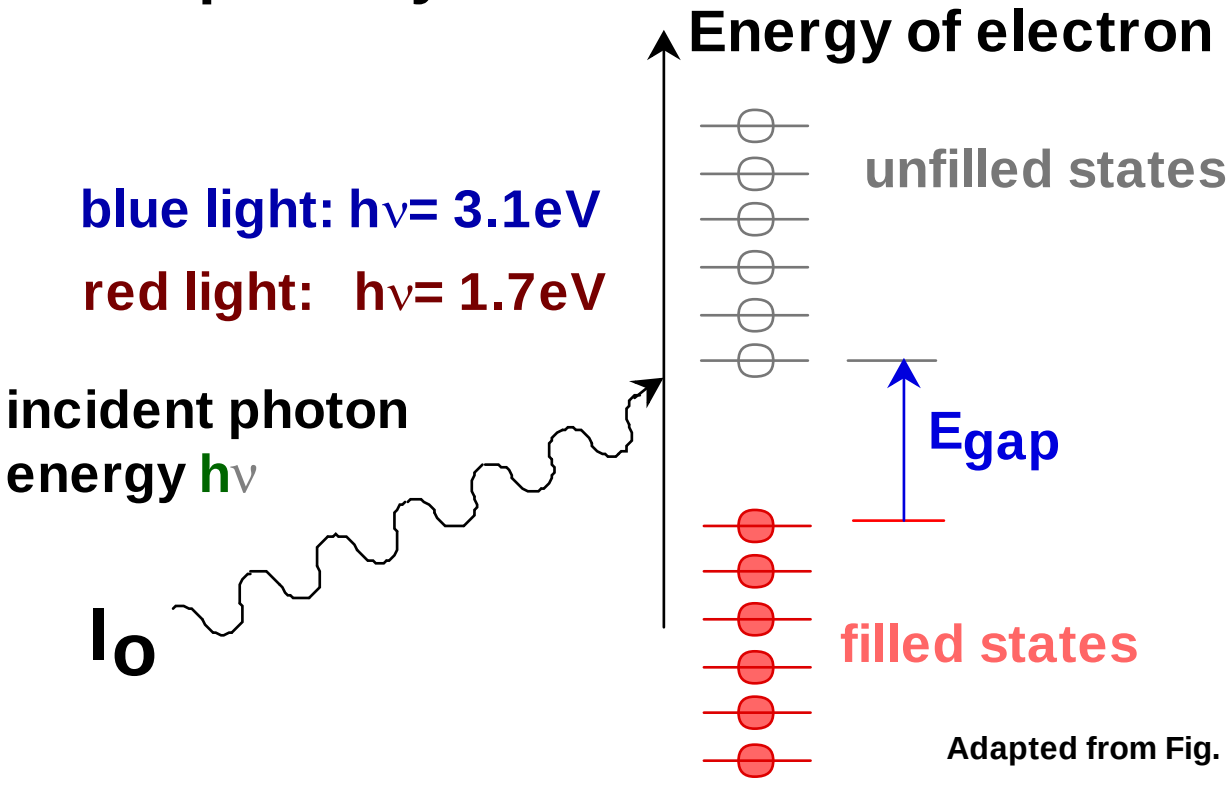


Adapted from Fig. 21.4(b), *Callister 6e*.

- **Reflectivity** = I_R/I_o is between 0.90 and 0.95.
- Reflected light is same frequency as incident.
- Metals appear reflective (shiny)!

SELECTED ABSORPTION: NONMETALS

- Absorption by electron transition occurs if $h\nu > E_{gap}$

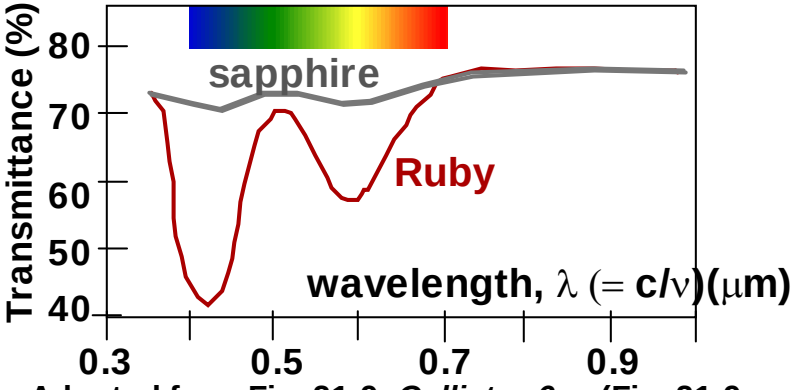


Adapted from Fig. 21.5(a), *Callister 6e*.

- If $E_{gap} < 1.8$eV, full absorption; color is black (Si, GaAs)
- If $E_{gap} > 3.1$eV, no absorption; colorless (diamond)
- If E_{gap} in between, partial absorption; material has a color.

COLOR OF NONMETALS

- Color determined by sum of frequencies of
  --transmitted light,
  --re-emitted light from electron transitions.
- Ex: Cadmium Sulfide (CdS)
  -- E_{gap} = 2.4eV,
  -- absorbs higher energy visible light (blue, violet),
  -- Red/yellow/orange is transmitted and gives it color.
- Ex: Ruby = Sapphire (Al_2O_3) + (0.5 to 2) at% Cr_2O_3
  -- Sapphire is colorless
  (i.e., E_{gap} > 3.1eV)
  -- adding Cr_2O_3 :
  - alters the band gap
  - blue light is absorbed
  - yellow/green is absorbed
  - red is transmitted
  - Result: Ruby is deep red in color.



Adapted from Fig. 21.9, *Callister 6e*. (Fig. 21.9 adapted from "The Optical Properties of Materials" by A. Javan, *Scientific American*, 1967.)

TRANSMITTED LIGHT: REFRACTION

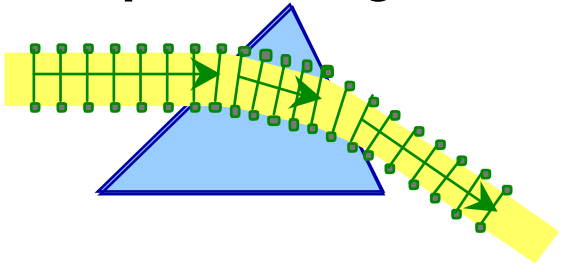
- **Transmitted light distorts electron clouds.**

- **Result 1: Light is slower in a material vs vacuum.**

$$\text{Index of refraction (n)} = \frac{\text{speed of light in a vacuum}}{\text{speed of light in a material}}$$

--Adding large, heavy ions (e.g., **lead**) can decrease the speed of light.

--Light can be "bent"



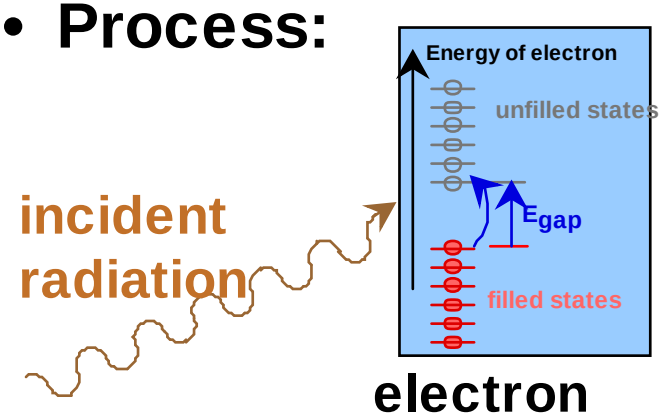
Material	n
Lead glass	2.1
Silica glass	1.46
Soda-lime glass	1.51
Quartz	1.55
Plexiglas	1.49
Polypropylene	1.49

Selected values from Table 21.1, *Callister 6e*.

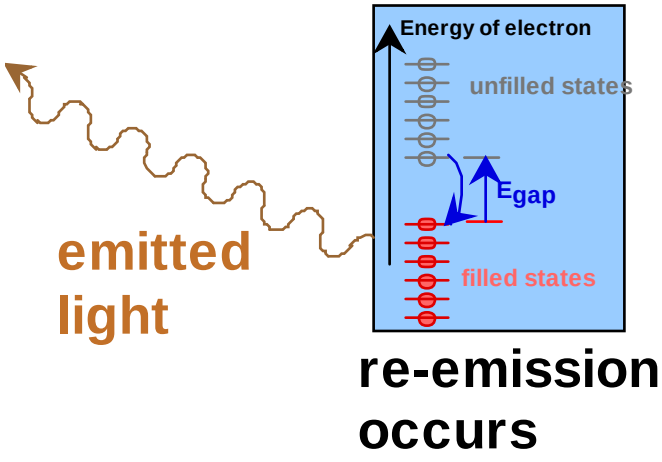
- **Result 2: Intensity of transmitted light decreases with distance traveled (thick pieces less transparent!)**

APPLICATION: LUMINESCENCE

- **Process:**

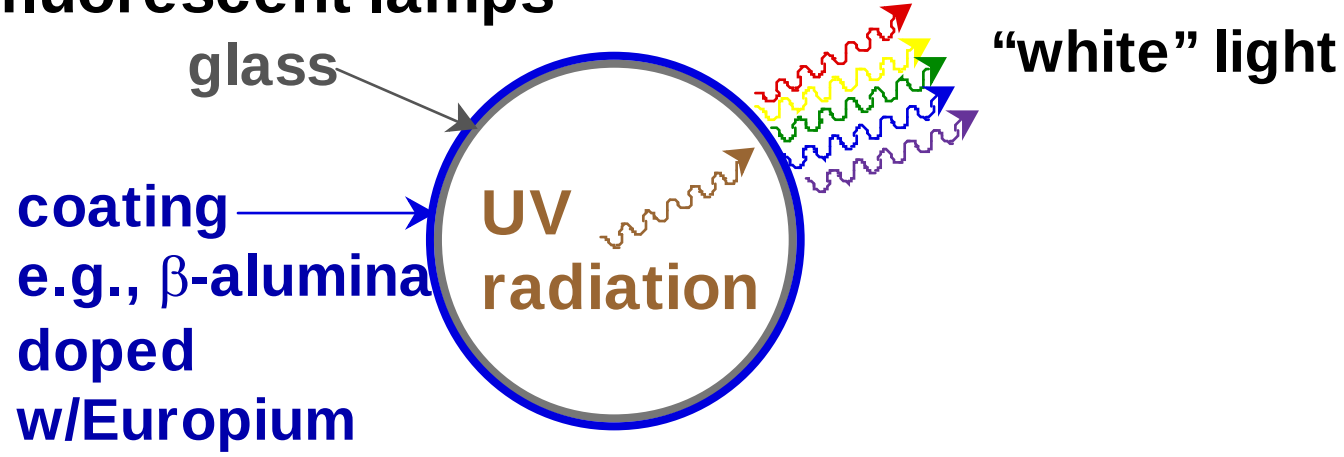


Adapted from Fig. 21.5(a), *Callister 6e*.



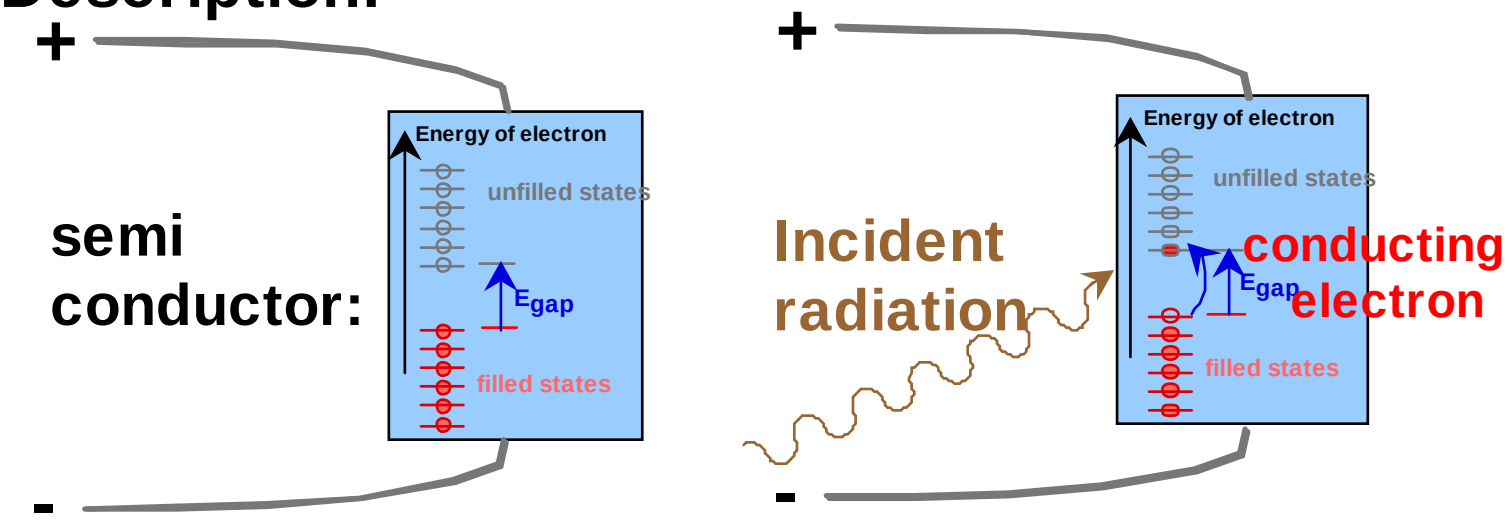
Adapted from Fig. 21.5(a), *Callister 6e*.

- **Ex: fluorescent lamps**



APPLICATION: PHOTOCONDUCTIVITY

- Description:



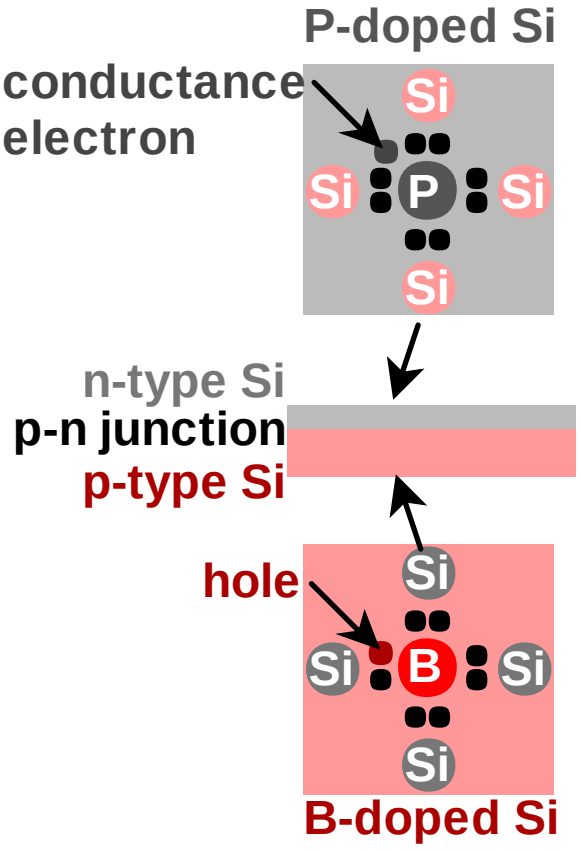
A. No incident radiation: little current flow

B. Incident radiation: increased current flow

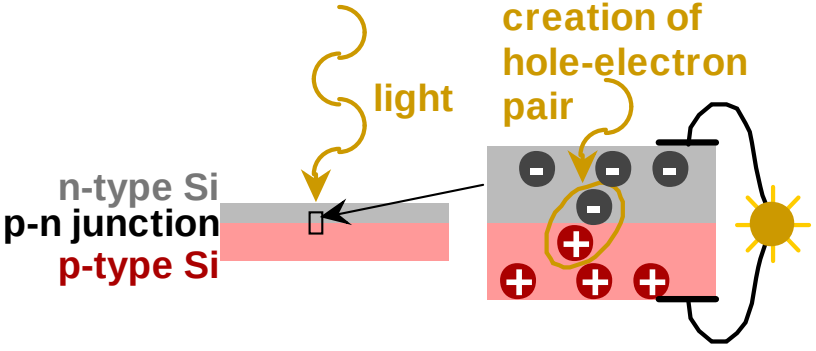
- Ex: Photodetector (Cadmium sulfide)

APPLICATION: SOLAR CELL

- **p-n junction:**



- **Operation:**
  - --incident photon produces hole-elec. pair.
  - --typically 0.5V potential.
  - --current increases w/light intensity.



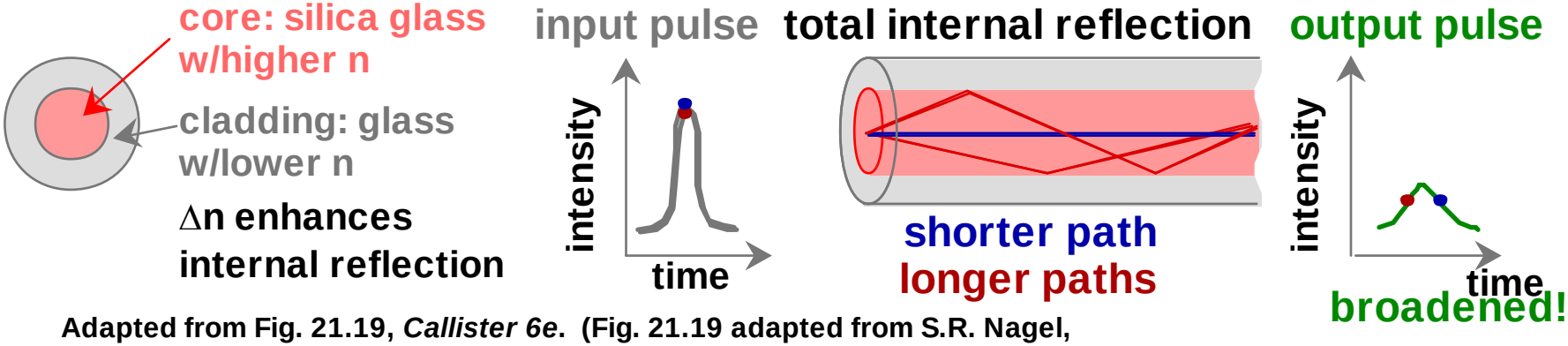
- **Solar powered weather station:**

polycrystalline Si

Los Alamos High School weather station (photo courtesy P.M. Anderson)

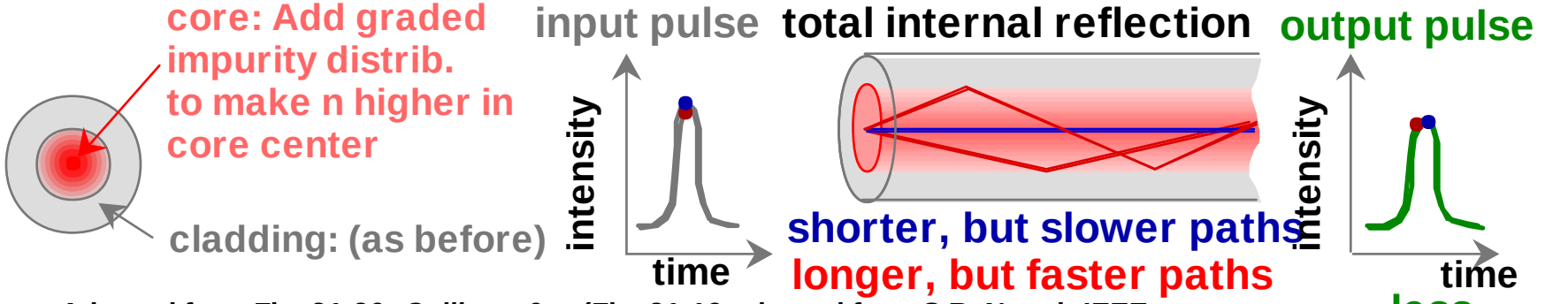
APPLICATION: FIBER OPTICS

- **Design with stepped index of refraction (n):**



Adapted from Fig. 21.19, *Callister 6e*. (Fig. 21.19 adapted from S.R. Nagel, *IEEE Communications Magazine*, Vol. 25, No. 4, p. 34, 1987.)

- **Design with parabolic index of refraction**



Adapted from Fig. 21.20, *Callister 6e*. (Fig. 21.19 adapted from S.R. Nagel, *IEEE Communications Magazine*, Vol. 25, No. 4, p. 34, 1987.)

- **Parabolic = less broadening = improvement!**

SUMMARY

- When light (radiation) shines on a material, it may be:
  --reflected, absorbed and/or transmitted.
- Optical classification:
  --transparent, translucent, opaque
- Metals:
  --fine succession of energy states causes absorption and reflection.
- Non-Metals:
  --may have *full* ($E_{gap} < 1.8eV$) , *no* ($E_{gap} > 3.1eV$), or *partial* absorption ($1.8eV < E_{gap} = 3.1eV$).
  --color is determined by light wavelengths that are transmitted or re-emitted from electron transitions.
  --color may be changed by adding impurities which change the band gap magnitude (e.g., Ruby)
- Refraction:
  --speed of transmitted light varies among materials.