White-light LEDs

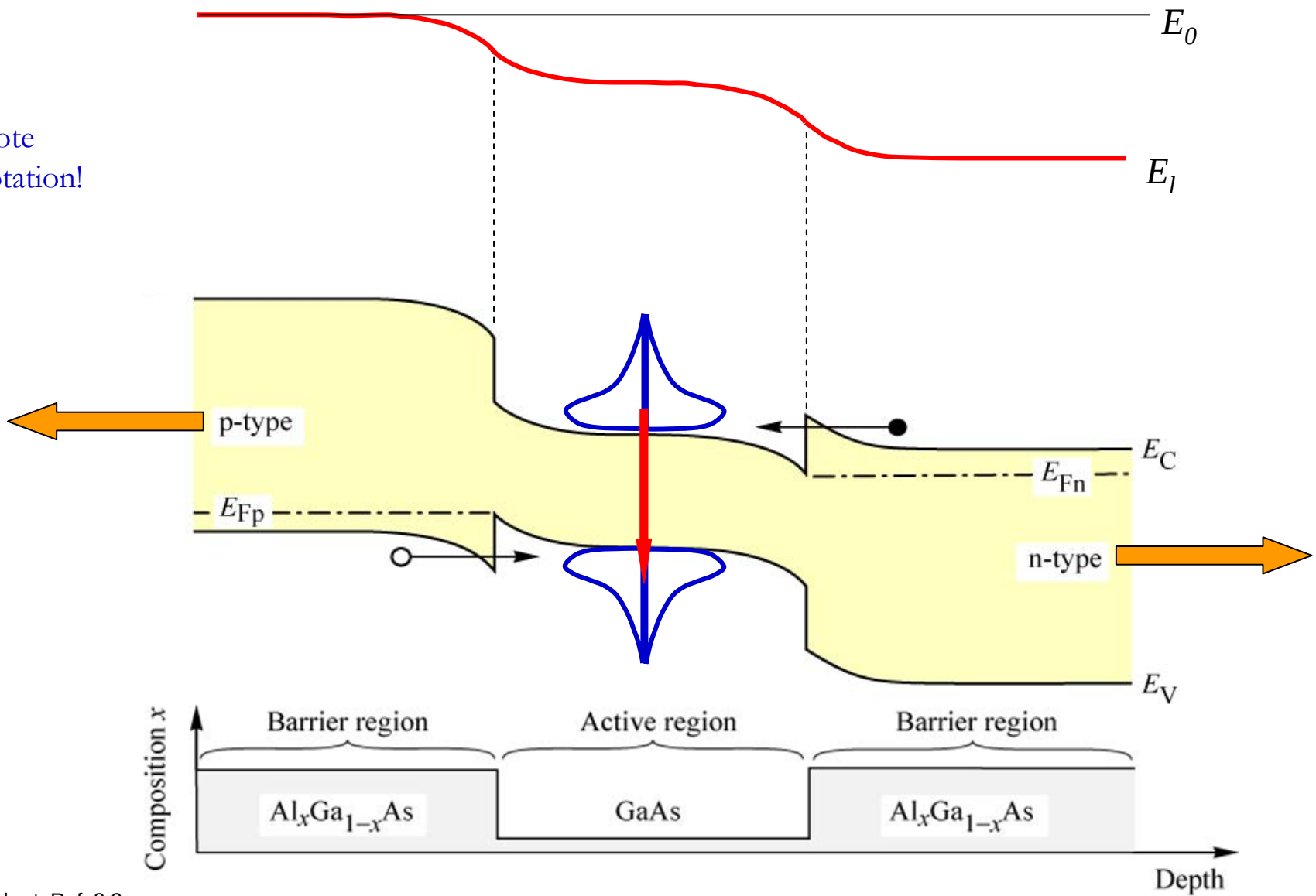
LECTURE 14

- Reminder of need for heterojunction structure
- Radiative recombination efficiency
- Extraction efficiency
- Various efficiencies
- White-light LEDs
- Prospects for general-purpose lighting

Sec. 8.2

Example of P⁺pN⁺ heterostructure LED

Note notation!



Schubert, Ref. 8.2

Next step in the design of LEDs

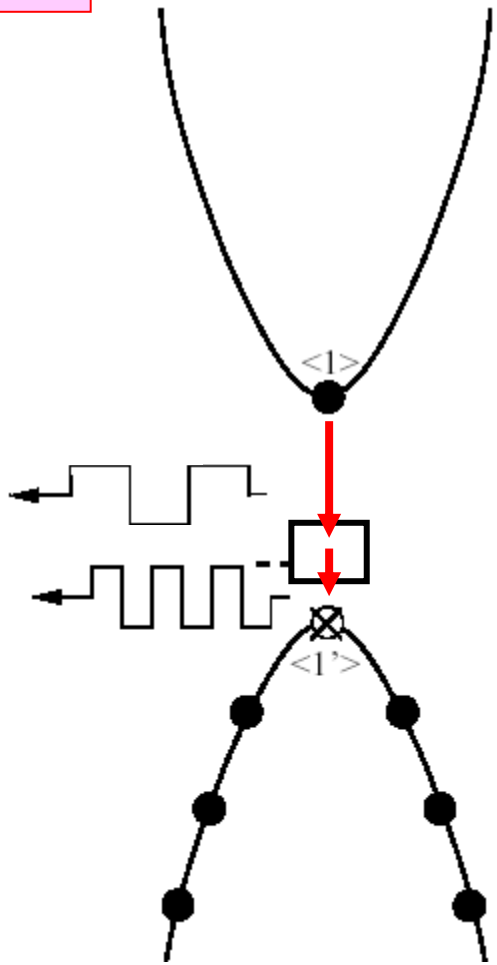
We have chosen the bandgap (to get the desired colour),

and we have chosen the structure (heterojunction diode) to get the confinement of the recombination.

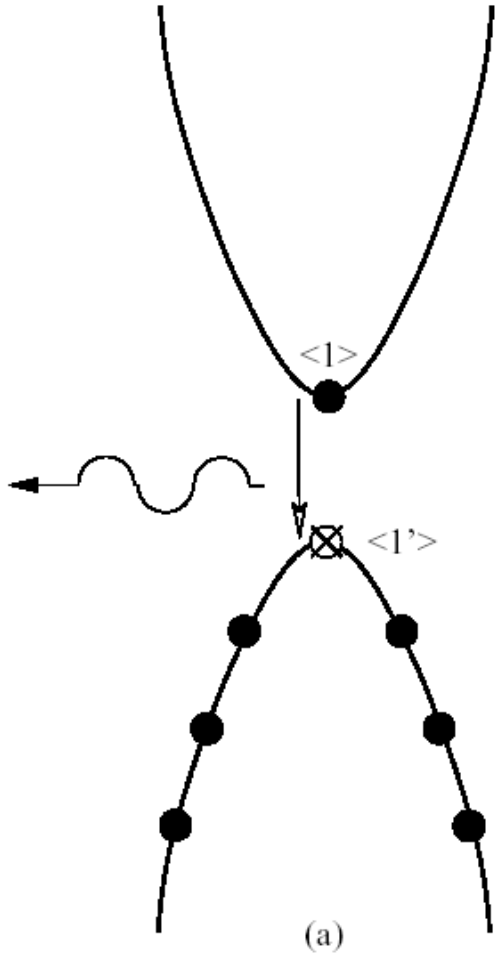
Now we have to make sure that the recombination is radiative, and not non-radiative.

Sec. 3.2.2, 3.2.3

Recombination mechanisms



RG-centre (SRH)



Radiative

$$R_{RG,} \approx rN_T n \equiv An$$ for p-type material

$$R_{rad} = Bnp$$

Sec. 3.2.4

Minority carrier lifetimes

Note the underlined terms

$$U_{\text{rad}} = Bnp - Bn_0p_0$$

$$\begin{aligned} np - n_0p_0 &= (n_0 + \Delta n)(p_0 + \Delta n) - n_0p_0 \\ &= \Delta n^2 + \Delta n(p_0 + n_0) \\ &\approx \Delta n^2 + \Delta np_0 \qquad \text{p-type material} \\ &= \Delta np_0 \qquad \text{low-level injection} \\ &= \Delta n(p_0 + \Delta n) \qquad \text{high-level injection}. \end{aligned}$$

$$U_{e,\text{rad}} \equiv \frac{\Delta n}{\tau_{e,\text{rad}}}$$

$$\begin{aligned} \tau_{e,\text{rad}} &= \frac{1}{Bp_0} \qquad \text{low-level injection} \\ &= \frac{1}{B(p_0 + \Delta n)} \qquad \text{high-level injection} \end{aligned}$$

- What is the expression for $\tau_{e,\text{R-G}}$?
- What is the expression for τ_e ?

Sec. 8.3

Radiative recombination efficiency

$$\eta_{\rm rad} =$$

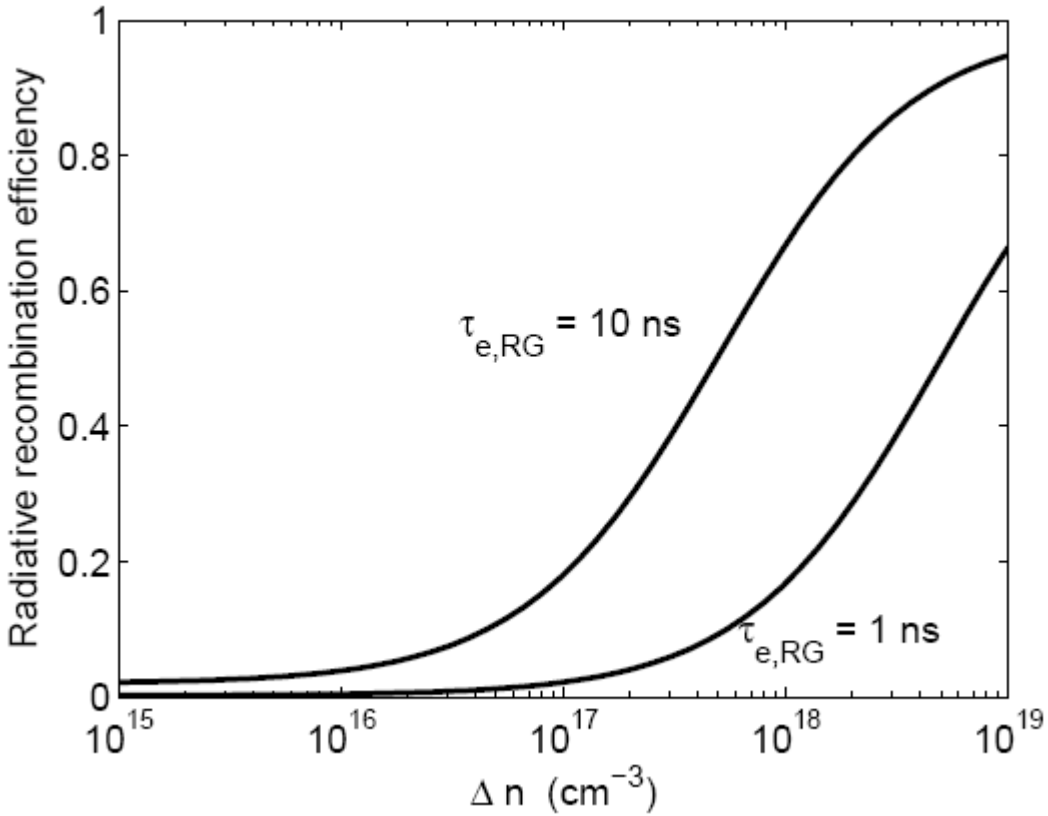
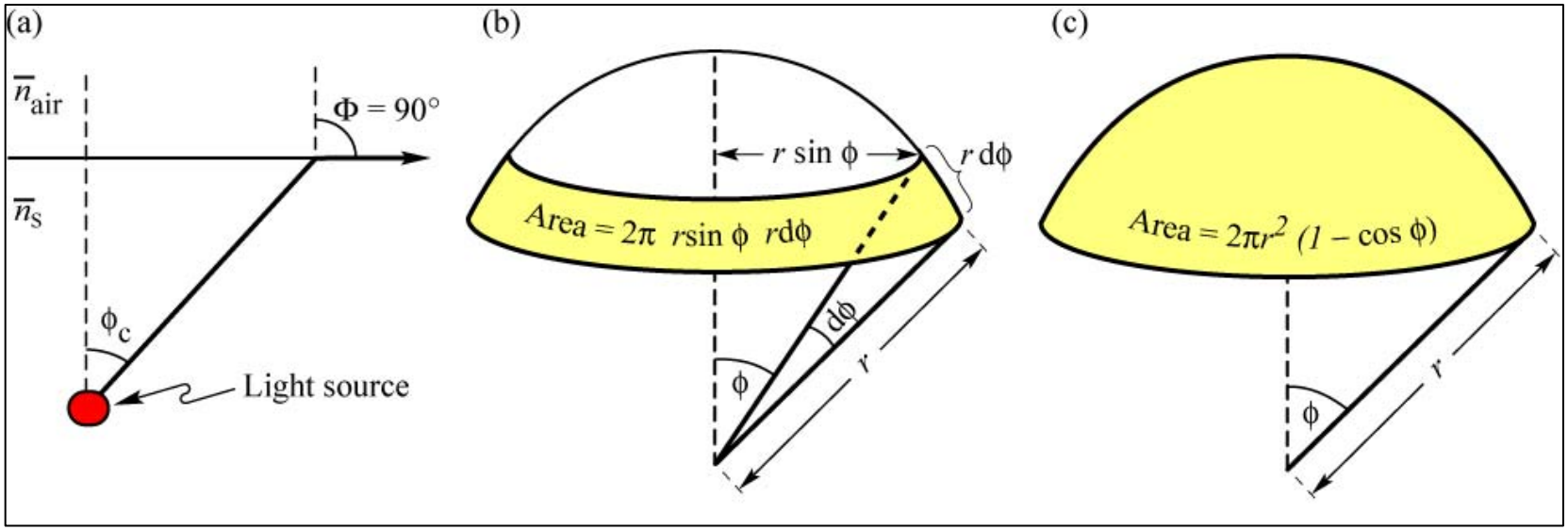


Figure 8.4: Radiative recombination efficiency for p-type GaAs of doping density $10^{16}\,\mathrm{cm}^{-3}$. The recombination parameters of Table 3.1 were used for the bottom curve. For the top curve, $\tau_{e,\mathrm{RG}}$ was increased by a factor of 10.

Sec. 8.4

Extracting the light



$$\eta_{ext} = \frac{S_{out}}{S_{gen}}$$

$$S_{out} = S_{gen}\frac{2\pi r^2(1-\cos\phi_c)}{4\pi r^2}$$

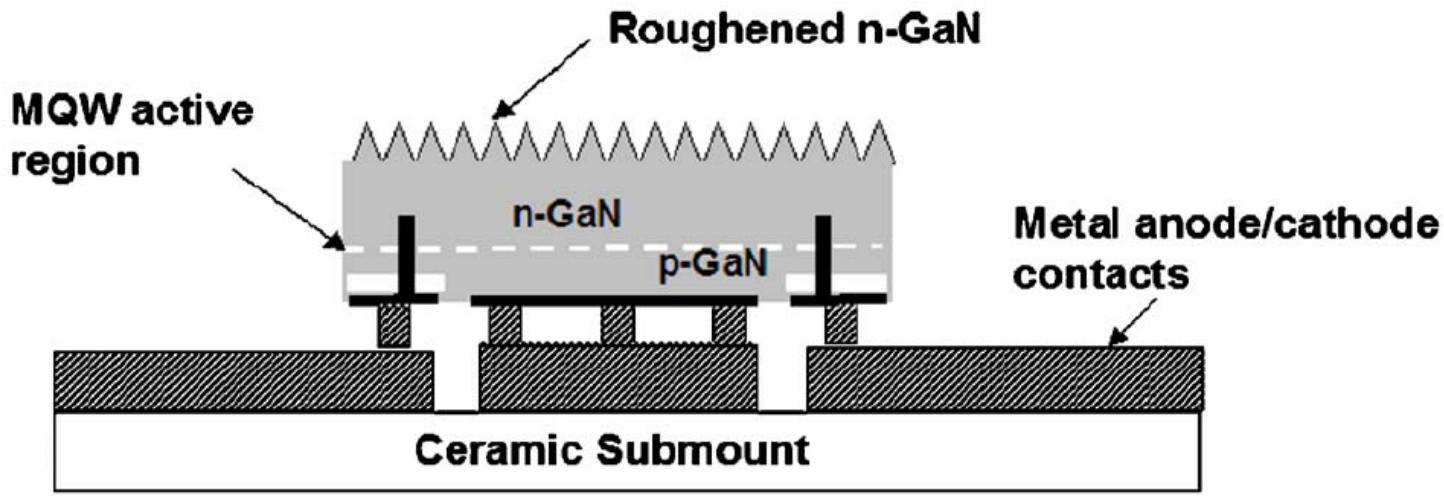
$$\phi_c = \arcsin(\frac{1}{3.5}) \approx 17^\circ$$

How much power gets out for GaAs?

Adapted from Schubert, loc. cit.

Sec. 8.4

Design to improve extraction efficiency



What are the features of this LED from Philips Lumileds that give it a high extraction efficiency?

From Shchekin, Lumileds, loc. cit.

Secs.
8.4, 8.5

Various efficiencies

$$S_{\text{out}} = (V_D \eta_V)\,(J_D \eta_C)\,\eta_{\text{rad}}\,\eta_{\text{ext}}$$

Wall-plug efficiency

$$\frac{S_{\text{out}}}{P_{\text{in}}} = \eta_V\,\eta_C\,\eta_{\text{rad}}\,\eta_{\text{ext}}$$

Present record is

Wall-plug efficiency is a radiometric measurement.

Light perception is personal, so photometric measurements are usually used in specifying LEDS., and are based on a standard eye-sensitivity function.

Sec. 8.7

Perception of light

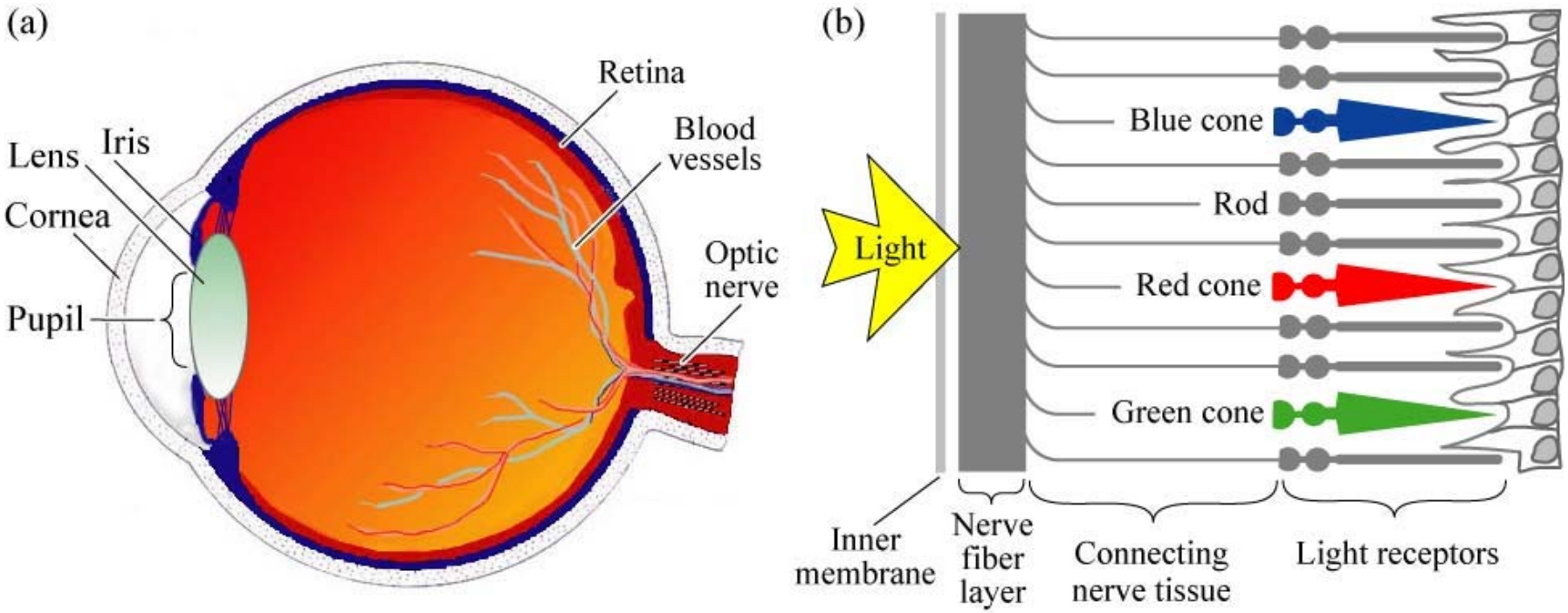
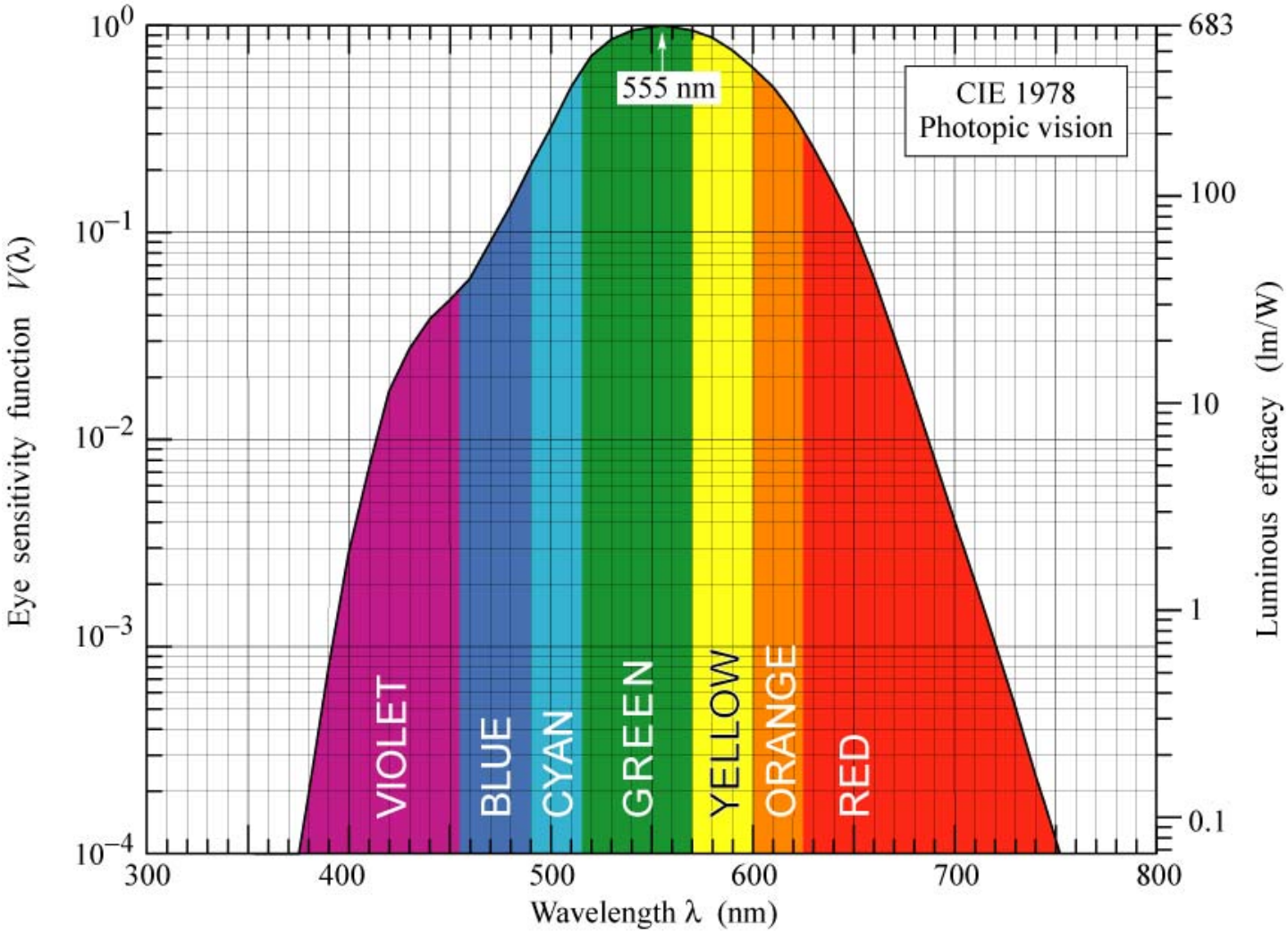


Fig. 16.1. (a) Cross section through a human eye. (b) Schematic view of the retina including rod and cone light receptors (adapted from Encyclopedia Britannica, 1994).

Sec. 8.7

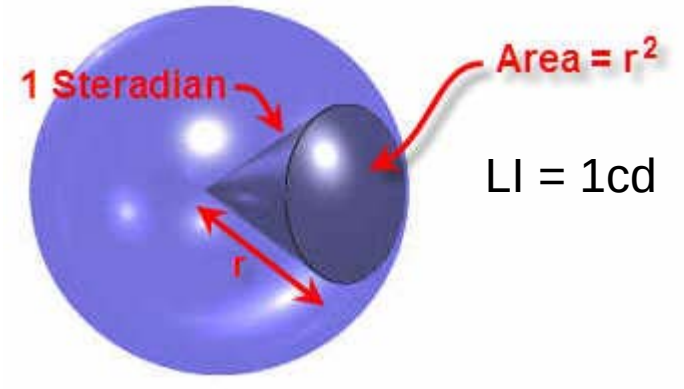
Eye sensitivity function



What is luminous efficacy?

Adapted from Schubert, loc. cit.

Photometric units



LI = 1cd

≡ 1/683 W @ 555nm

LI = luminous intensity

Integrate over sphere → LF = 4π lm

50W halogen = 900 lm

LF = luminous flux

$$\Phi = 683 \int_{\lambda} \gamma S'_{\text{out}}(\lambda)\, d\lambda \quad \text{(lumens)}. \tag{8.13}$$

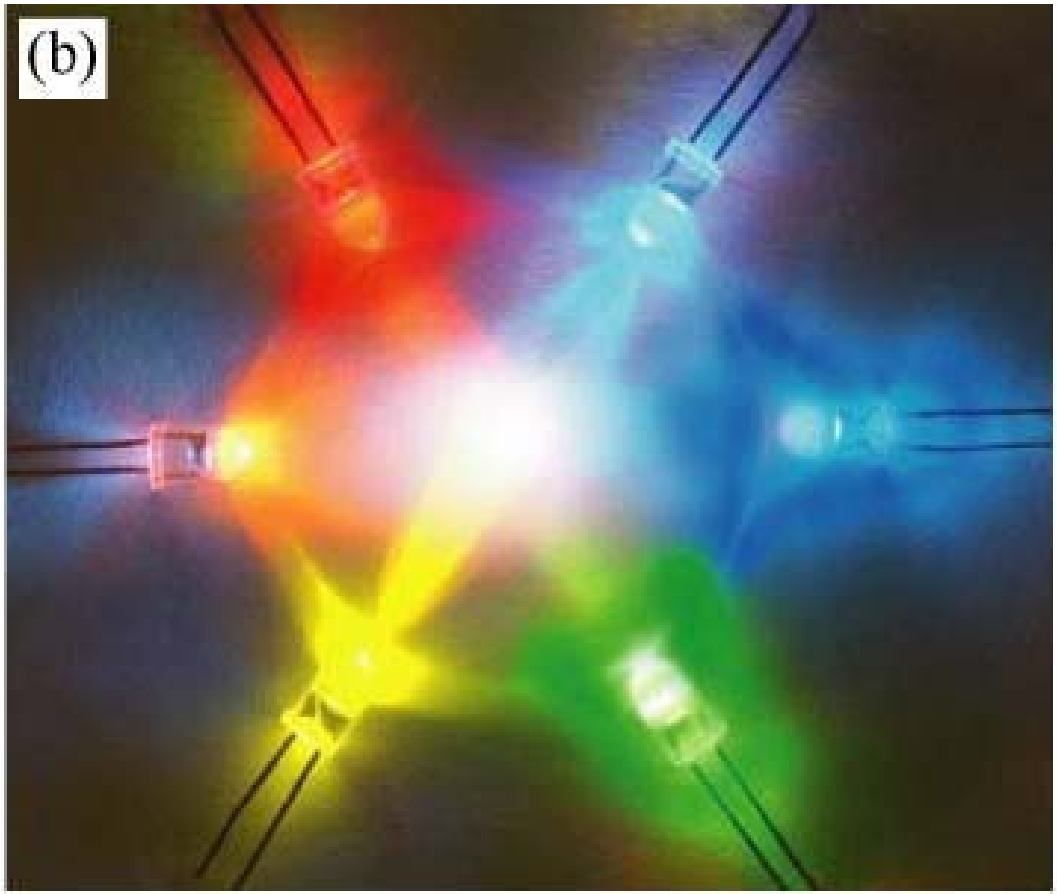
The **luminous efficacy** measures the effectiveness of the eye in perceiving optical power:

$$\text{luminous efficacy} = \frac{\Phi}{S'_{\text{out}}} \quad \text{(lm/W)}. \tag{8.14}$$

LE = luminous efficiency (lm/$W_{electrical}$)

Sec. 8.7

Additive LEDs

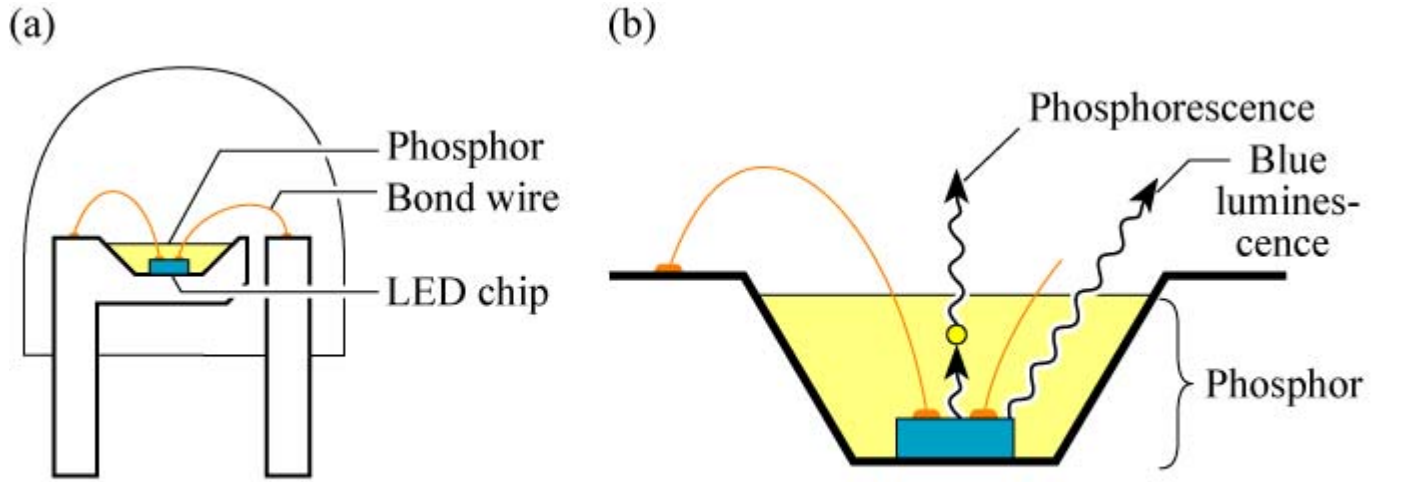


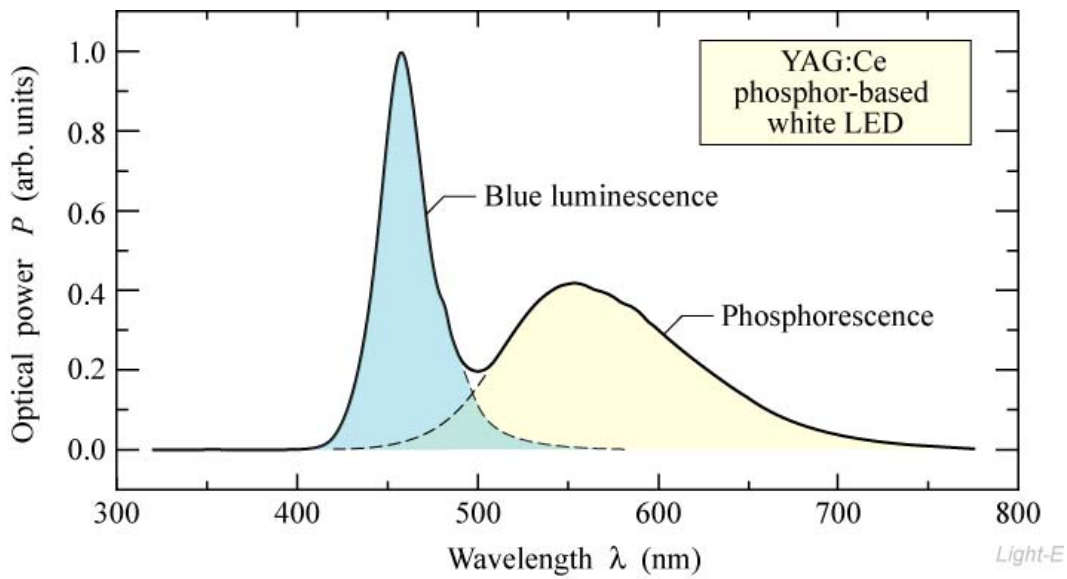
Light-

From Schubert, loc. cit.

Sec. 8.7

Blue/yellow phosphor LEDs

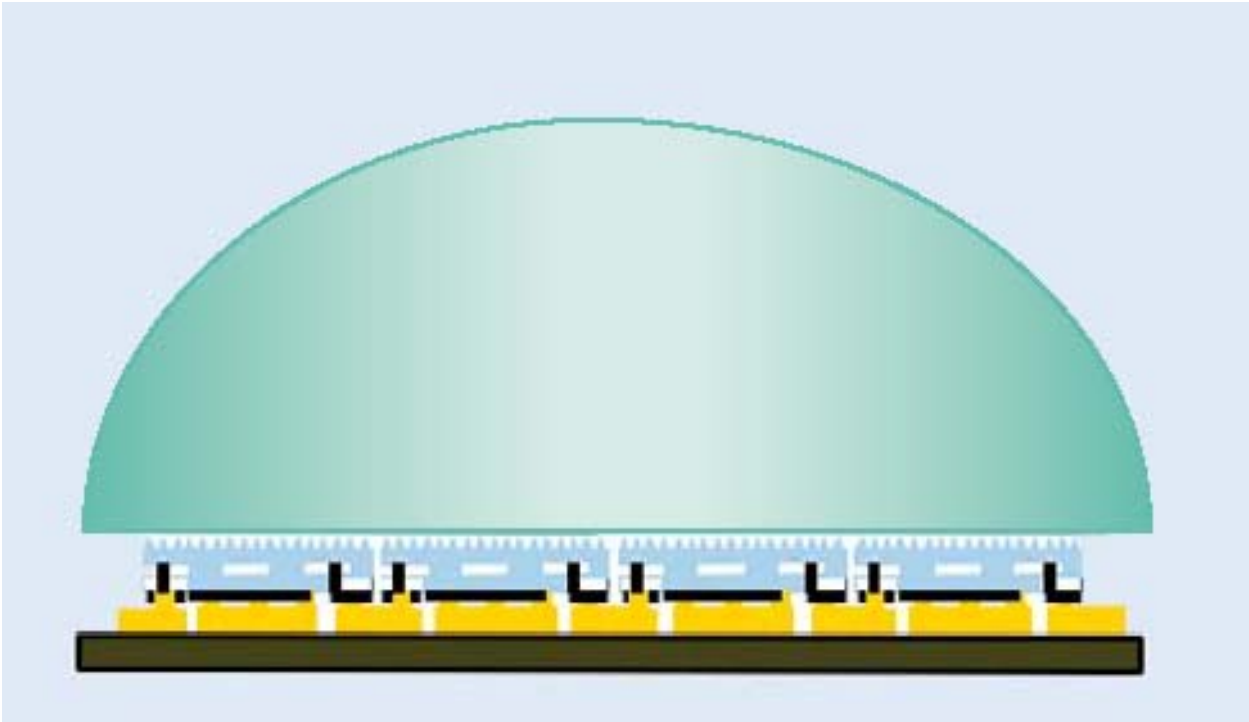




Adapted from Schubert, loc. cit.

Sec. 8.7

High-brightness with phosphor dome



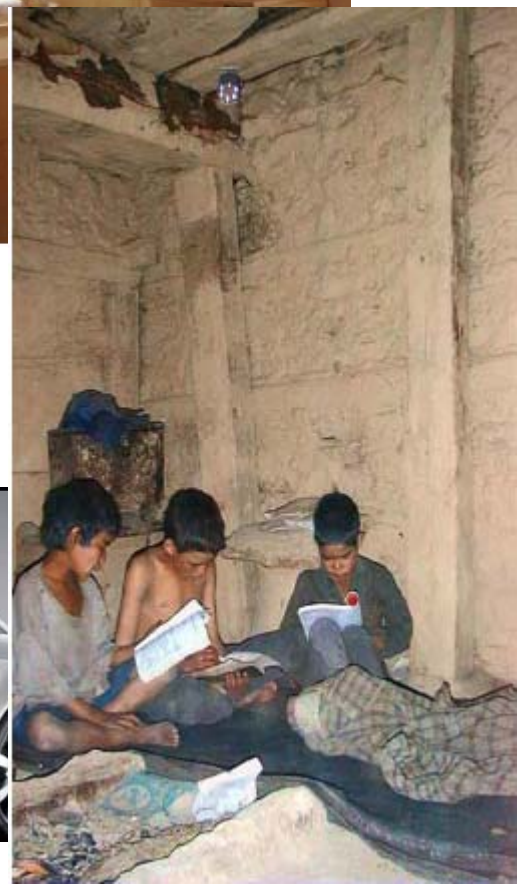
From Shchekin, Lumileds, loc. cit.

Light bulb comparison

	W	lumens	khours	CRI	$US
Incandescent (long life)	75	(1200)	10	(95)	1.75
W-halogen (PAR38)	75	940	5	(95)	5.95
Fluorescent (T10 tube)	40	3550	20	84	6.95
Fluorescent (compact)	20	1295	12	82	4.95
LED (PAR20, warm)	9	400	40	77	58.95

Data: 12 April, 2010: BuyLighting.com

LEDs: white



M.G. Craford, Lumileds Lighting