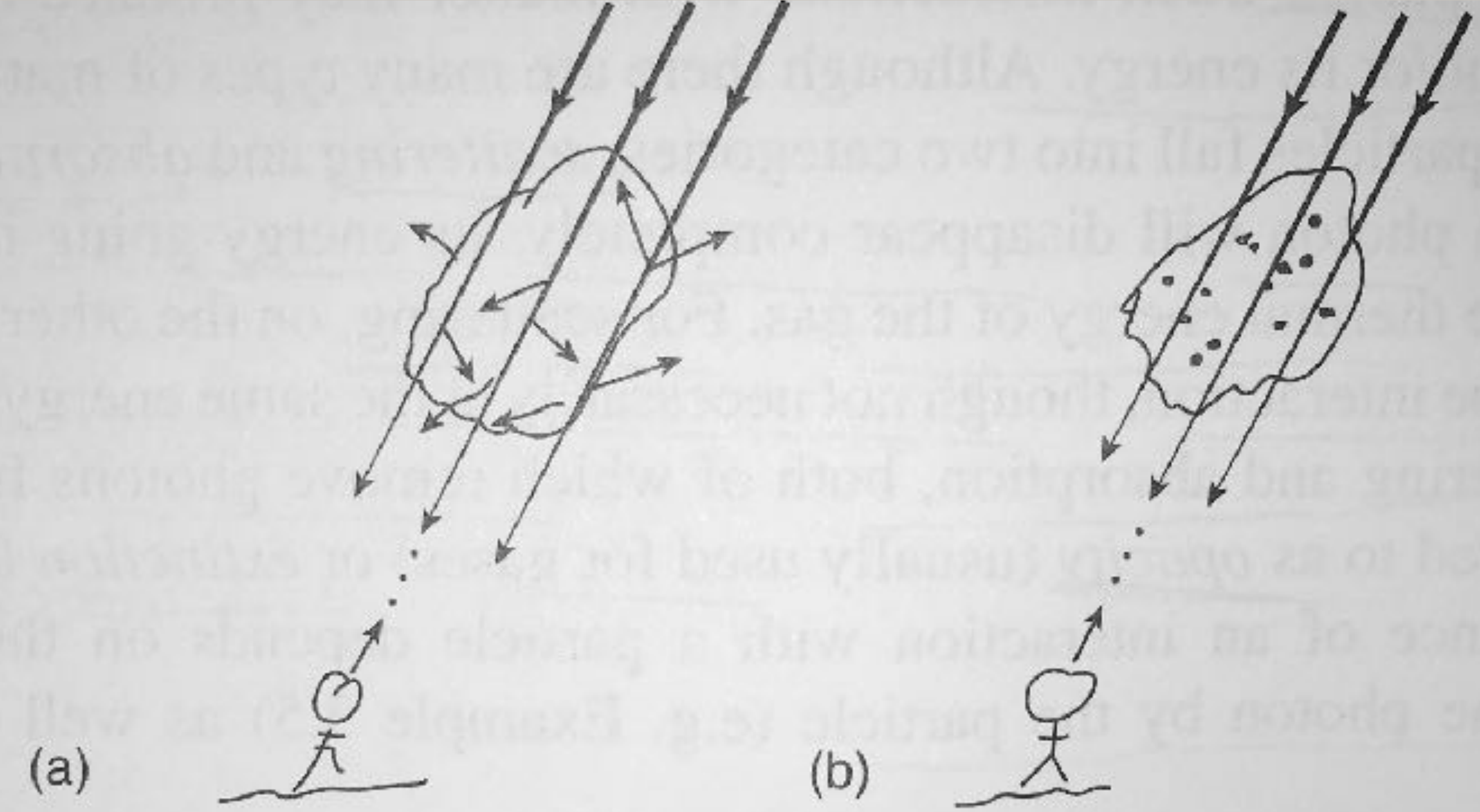


Figure 5.1. Illustration of **(a)** random scattering and **(b)** absorption along a line of sight. The observer is meant to be far from the source as well as the scattering medium in this diagram. Darker arrows convey a more intense signal.

Scattering: interaction ⟹ change of direction

absorption: photon lost. \ can include absorption.

Ex of abs: ⟶ dust grain ← heats the grain

⟶ atom – ionization

⟶ atom excitation followed by collision

Examples of Scattering

- elastic (particle), coherent (wave) "bounce"

  $h\nu = h\nu'$ i.e no change in energy or λ
  incoming outgoing

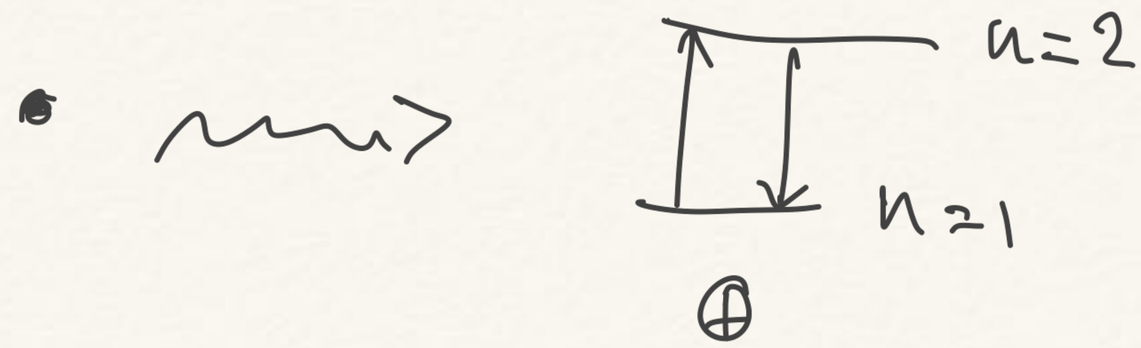
  - Thomson scattering ionized gas (or partially ionized)

    $\rightsquigarrow e^-$ $\Rightarrow$ free e^-

    if $E_{\nu\,\text{incoming}} \ll m_e c^2$ (rest mass of e^-)

    then elastic (otherwise some $E \to e^-$)

    very common whenever ionized gas!

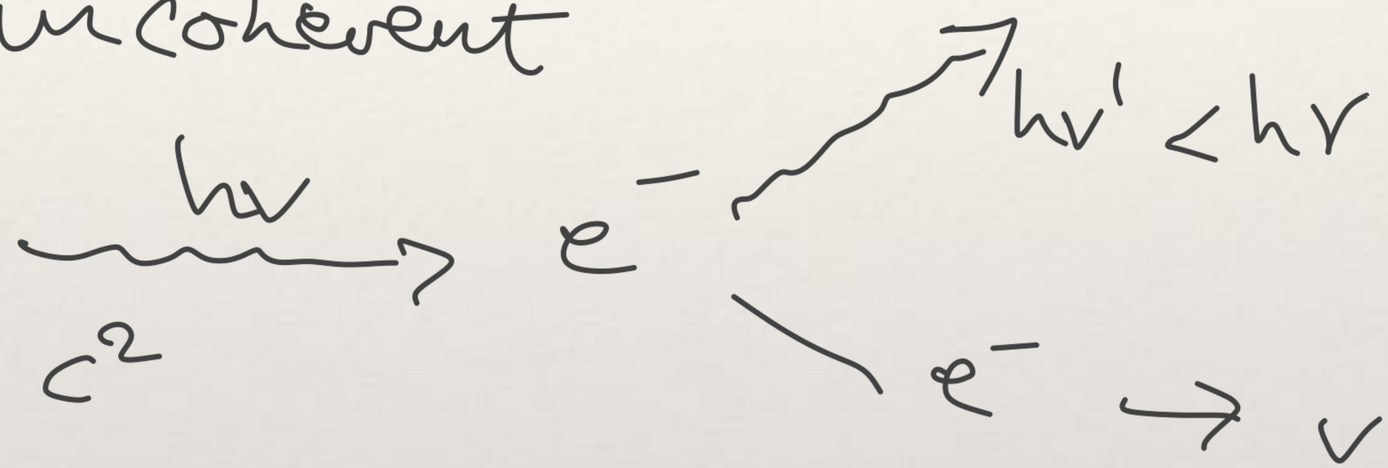
- 

excitation followed by de-excitation

λ same!

resonance scattering

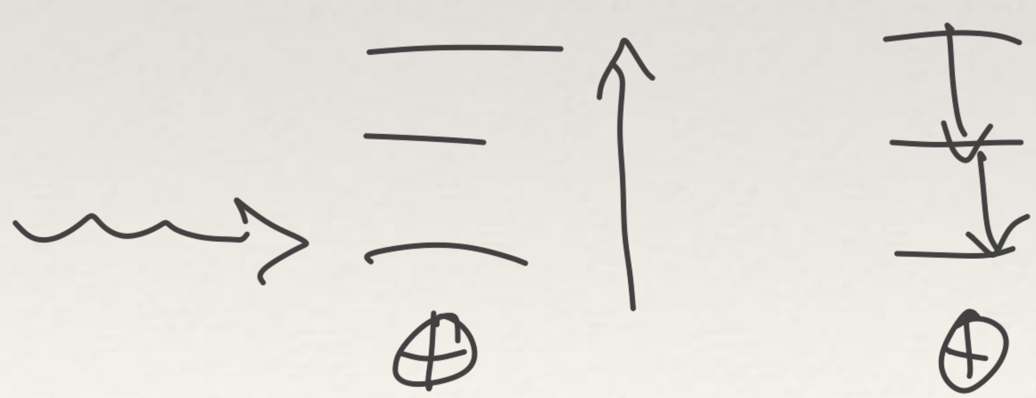
- Inelastic, incoherent



$h\nu \geq m_e c^2$

Compton scattering

Example



turns one photon into two of lower energy

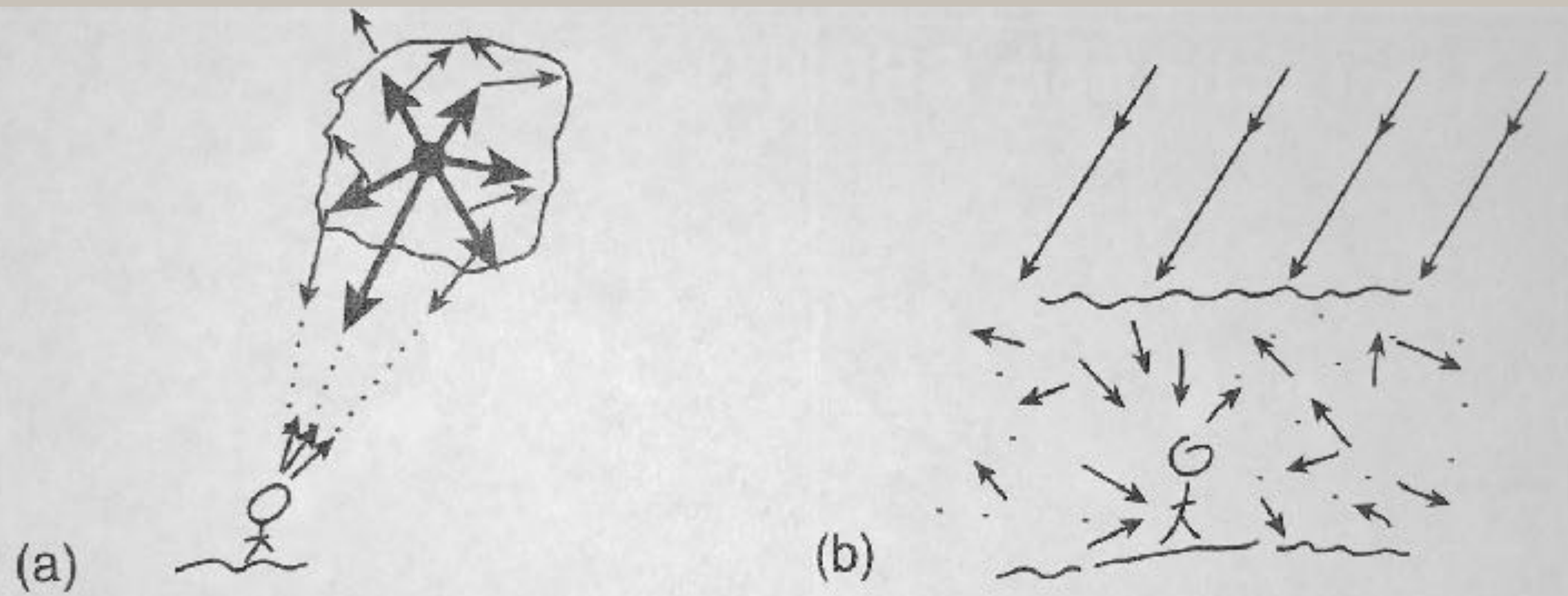


Figure 5.2. Two examples of scattering into the line of sight. **(a)** Dust particles surrounding a star scatter its light randomly, but some of these photons will be directed towards the observer. Thus, the observer sees a faint glow around the star, much like the glow around a streetlight on a misty night. **(b)** When the observer is within a randomly scattering medium, light can enter his eye from all directions even though the original source of light is in one direction only.

possible to scatter photons into your los

a) dust around a star - random, some to observer

⇒ glow around the star

= reflection nebula : light source inside scattering medium

b) e.g sky

How tell if light is scattered?

- geometry is a clue
- polarization

$$D_p = \frac{I_{pol}}{I} \quad \leftarrow \text{fraction of polarized light}$$

$$\left(I = I_{pol} + I_{unpol} \right)$$

↑ degree of polarization

Merope (Pleiades) reflection nebula

M20, the Trifid nebula reflection nebula and HII region

Observer ⊥ to polarizer ⇒ can see polarized light

Thomson or Rayleigh scattering: unpol ⇒ pol

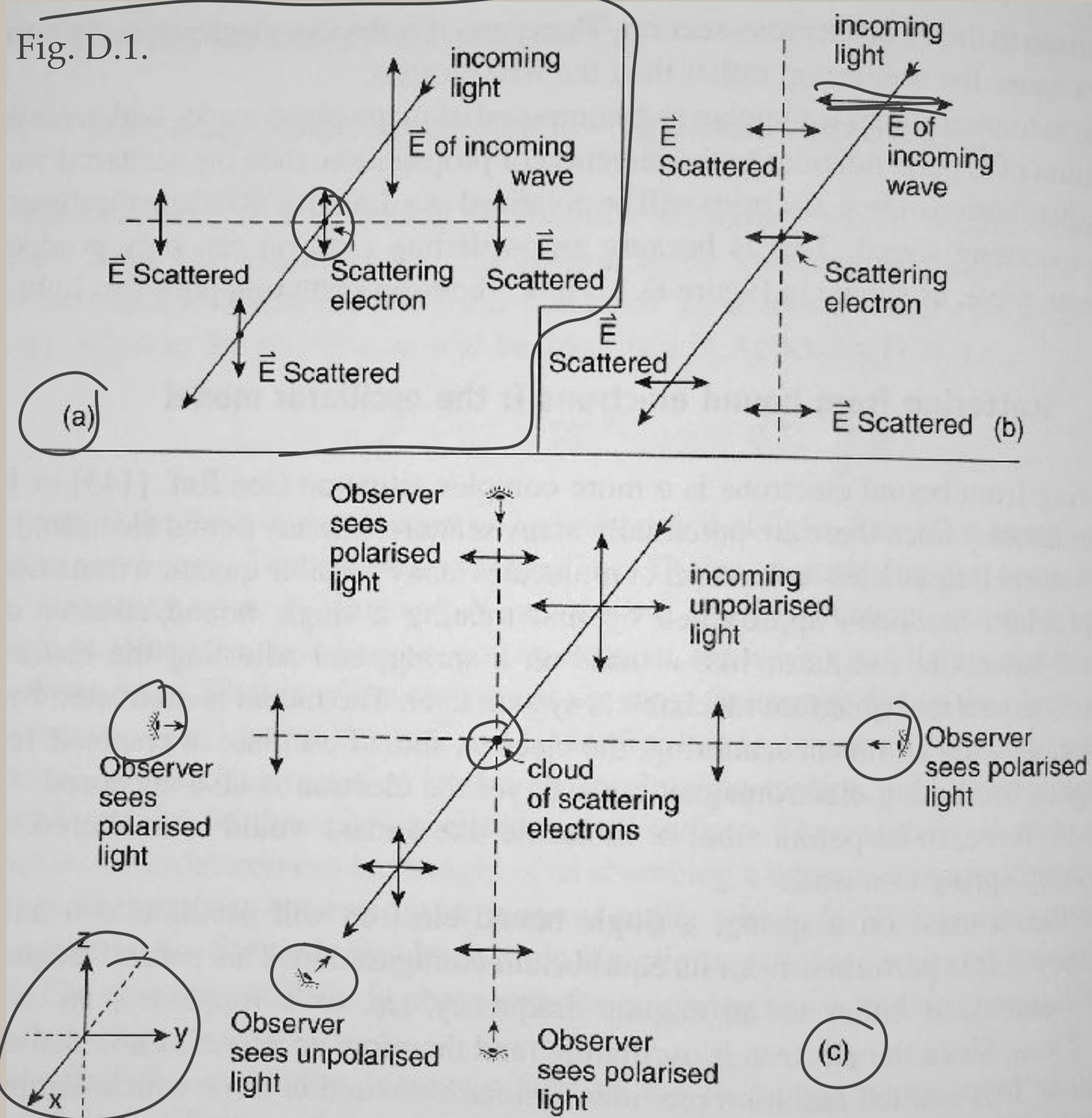
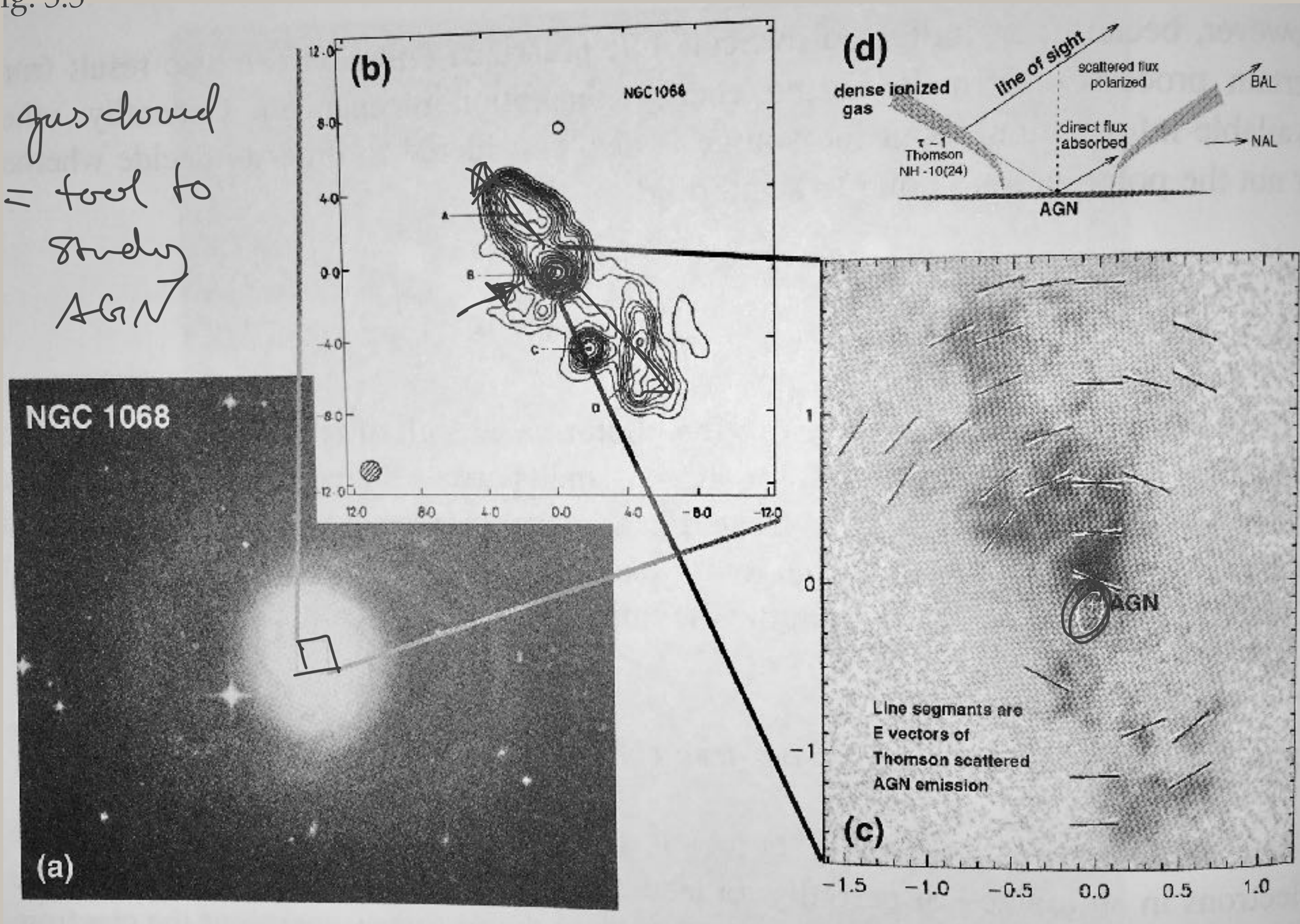


Fig. D.1.

Fig. 5.5



gas cloud = tool to study AGN
NGC 1068
(a)
(b)
NGC 1068
A
B
C
D
(c)
AGN
Line segmants are E vectors of Thomson scattered AGN emission
(d)
dense ionized gas
line of sight
scattered flux polarized
direct flux absorbed
τ ~1 Thomson NH ~10(24)
AGN
BAL
NAL

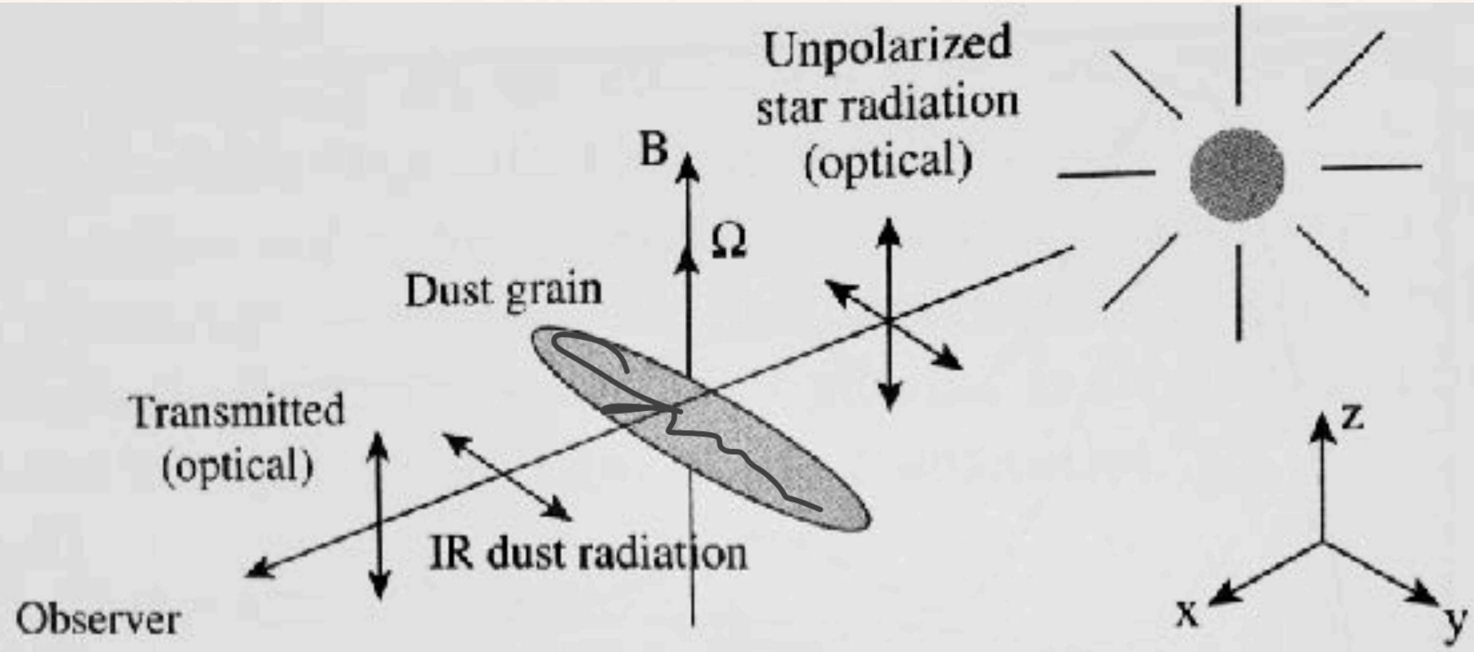


Figure D.6. An unpolarized signal from a background star becomes polarized as it interacts with an elongated dust grain that rotates about a magnetic field line. In this example, the magnetic field is parallel to the *z* axis and light propagates in the *x* direction. Incident light that has $\vec{E}$ in the *y* direction is more likely to be absorbed than waves that have $\vec{E}$ in the *z* direction, letting the light that has a *z* orientation pass through more easily. Thus, the transmitted light is polarized in a plane aligned with the magnetic field. A charged dust grain that absorbs some fraction of incident light would also re-emit it in the infrared. The emitted light would be polarized in a plane perpendicular to the magnetic field

$\Rightarrow$ polarization in a plane aligned with $\mathbb{B}$ (the absorbed light $\Rightarrow$ IR pol. other direction)

Now, cross-sections σ (table 5.1)

3 cases

1) free e^- scattering

2) bound e^- —"— ← more complex

3) dust —"—

---

1) a) Thomson $\sigma = \sigma_T = 6.65 \cdot 10^{-25}\ cm^2$

b) Compton (photon energy higher than rest mass energy of e^-, often γ-ray photons

$\sigma = \sigma_{KN}$ = "Klein-Nishima" cross section

quantum & relativistic effects

decrease in σ with increasing photon energy.

$\Rightarrow$ less efficient scattering when $\nu \uparrow$

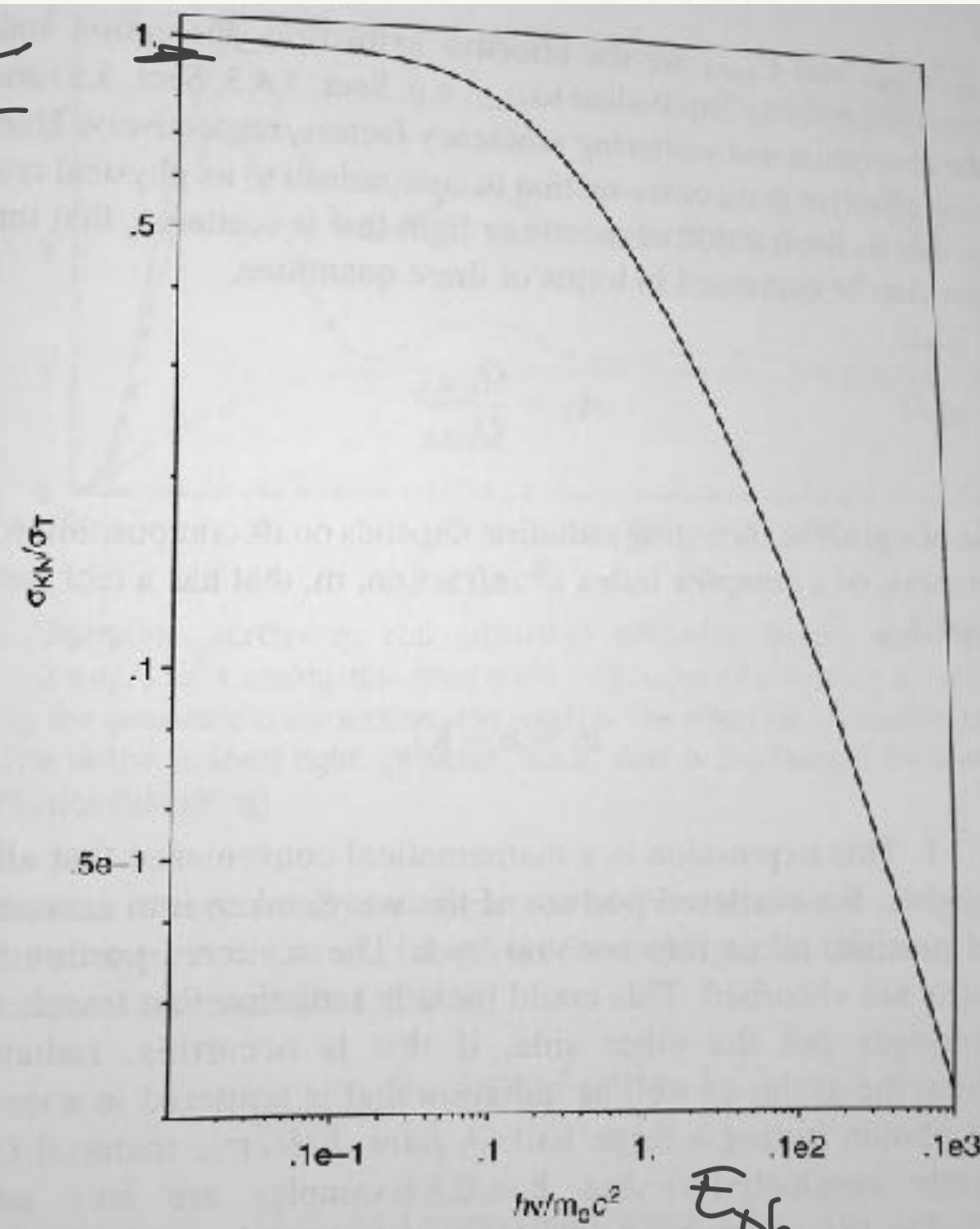


Figure D.4. Ratio of the Klein–Nishina cross-section to the Thomson cross-section, σ_{KN}/σ_T as a function of the parameter, $h\nu/m_e c^2$, showing the decrease in cross-section with increasing photon energy.

2) scattering from bound e^-

a) oscillator model

$\nu \gg \nu_0$ ← natural ν of oscillator

ν of radiation field

e^- responds as if free

$\sigma_s = \sigma_T$

b) $\nu \sim \nu_0$ (classical) — resonance scattering

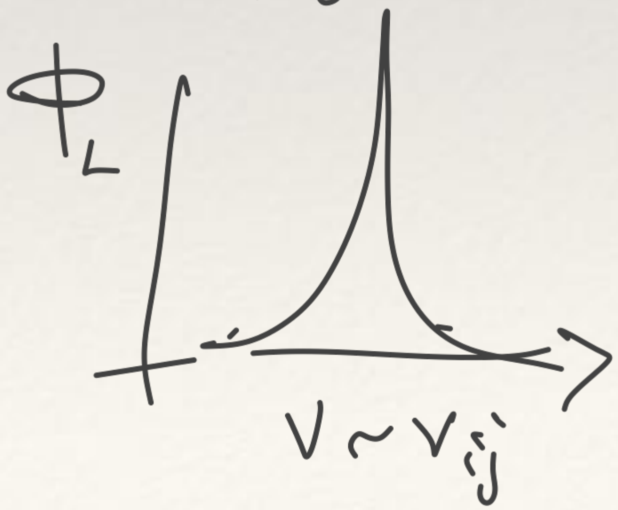
$\nu \sim \nu_{ij}$ (quantum)

also gives a polarized signal

$\sigma_s \propto \phi_L(\nu)$ Lorentz profile

fig D.2

Some probability photon emitted at different ν



c) $\nu << \nu_0$ $\quad \lambda >> \lambda_0$

recall deBroglie model : $n\lambda_0 = 2\pi r$

$\lambda >> \lambda_0$ same as $>> r$ (particle size)

Rayleigh scattering (see eq D.10 and discussion)

$$\sigma_s \propto \frac{1}{\lambda^4}$$

N_2 O_2 size ~ 0.3 nm