Introdução à Astronomia
Prof. Antônio Kanaan
Aula 4 –
Propriedades da Luz
Instrumentos Astronômicos

Créditos:

A maioria das figuras da aula de hoje vêm de:

1) Chaisson

2) Hypershysics
(http://hyperphysics.phy-astr.gsu.edu/hbase/hframe.html)

Informação vem em forma:

1 – luz (ondas eletromagnéticas)

2 – ondas gravitacionais

3 - neutrinos

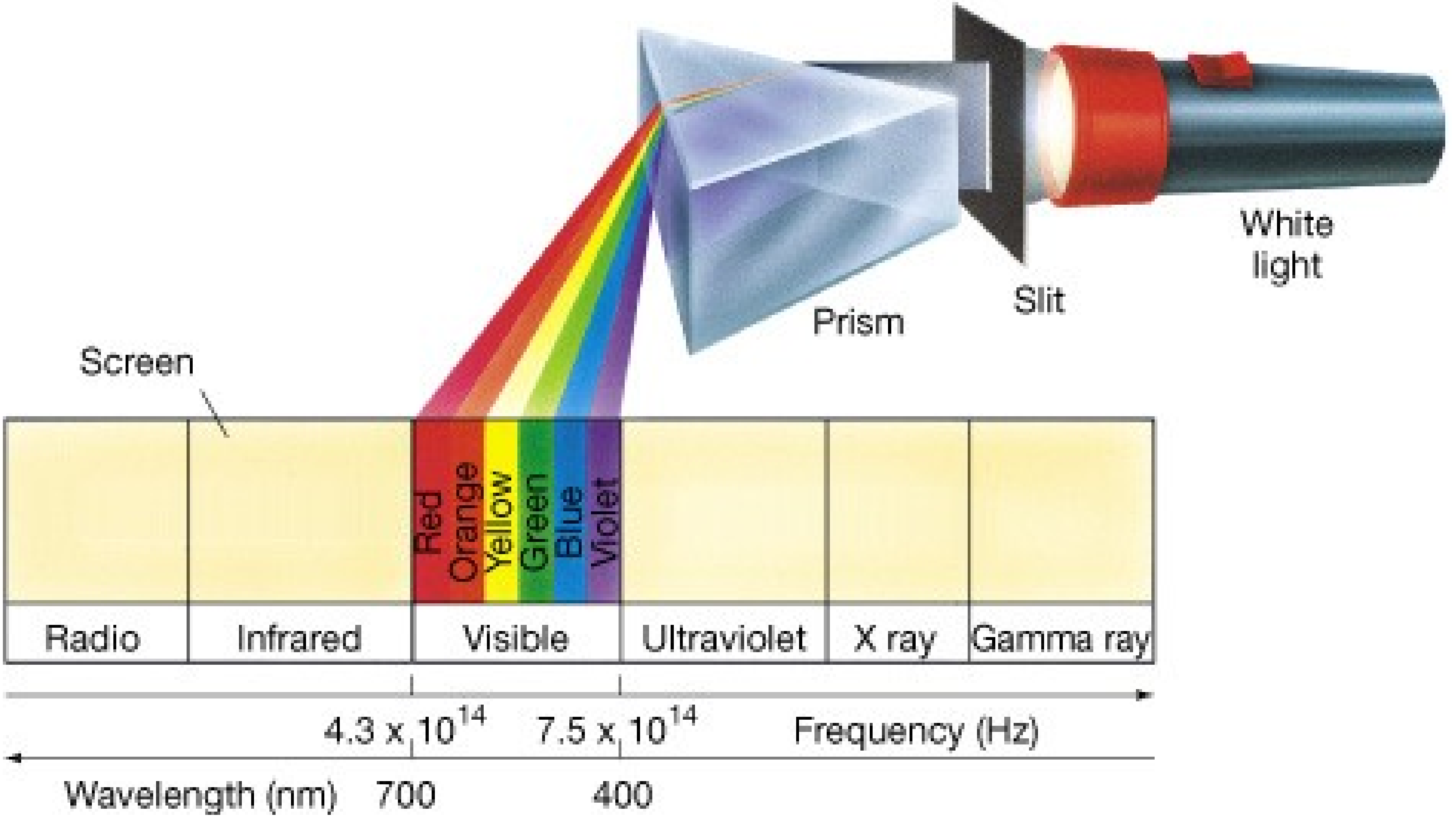
O que é a luz?

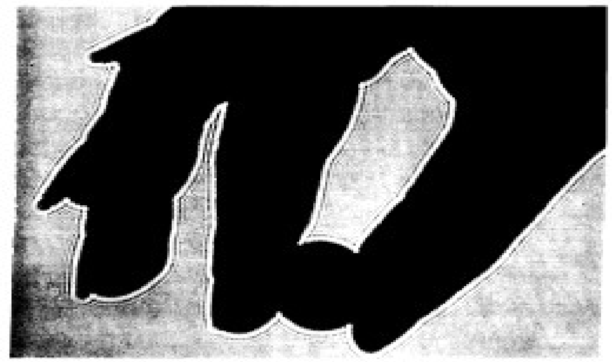
Onda? Partícula? como este é um curso de astronomia e não de física não discutiremos muito sobre a natureza da luz, que é um assunto fascinante.

História curta:

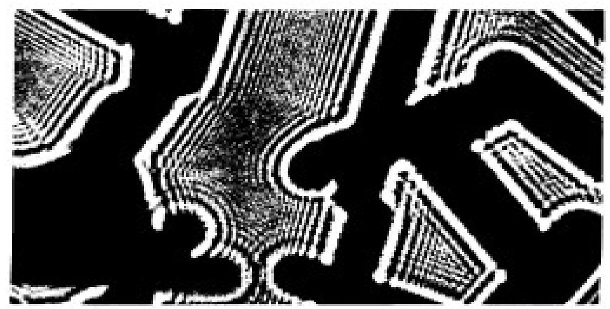
Newton - defensor da teoria corpuscular

Huygens – defensor da teoria ondulatória


White light
Slit
Prism
Screen
Red
Orange
Yellow
Green
Blue
Violet
Radio
Infrared
Visible
Ultraviolet
X ray
Gamma ray
4.3 x 10^14
7.5 x 10^14
Frequency (Hz)
Wavelength (nm)
700
400

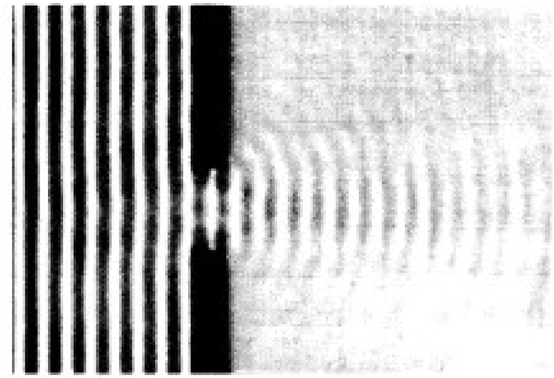


(a)

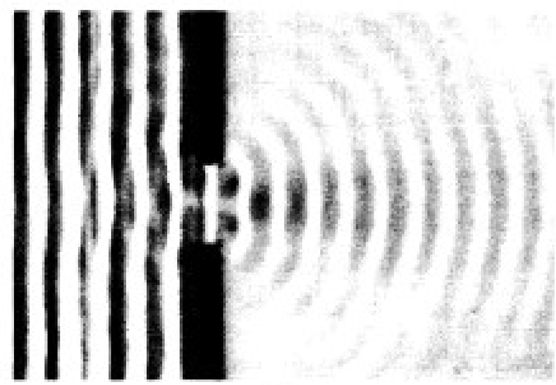


(b)

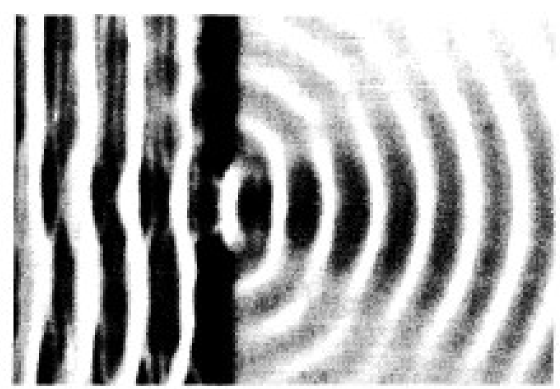
(*a*) The shadow of Mary's hand holding a dime, cast directly on 4 × 5 Polaroid A.S.A. 3000 film using a He–Ne beam and no lenses. (Photo by E. H.) (*b*) Fresnel diffraction of electrons by zinc oxide crystals. (After H. Boersch from *Handbuch der Physik*, edited by S.Flugge, Springer-Verlag, Heidelberg.)



(a)

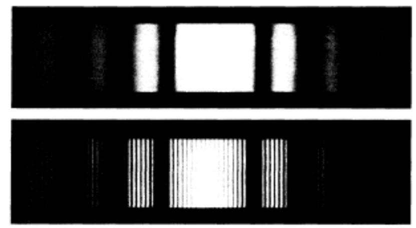


(b)

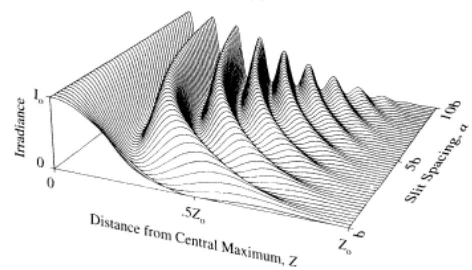


(c)

Diffraction through an aperture with varying λ as seen in a ripple tank.
(Photo courtesy PSSC *Physics*, D. C. Heath, Boston, 1960.)



(a)

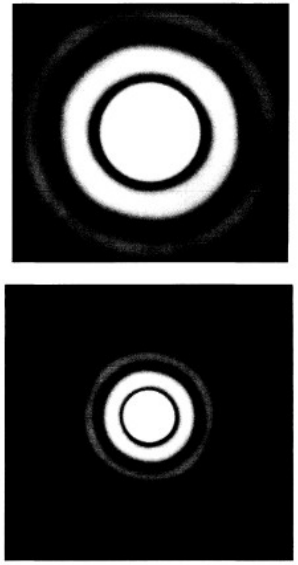


(b)

Figure 10.14 Single- and double-slit Fraunhofer patterns. (*a*) Photographs taken with monochromatic light. The faint cross-hatching arises entirely in the printing process. (Photos courtesy M. Cagnet, M. Francon, and J. C. Thrierr: *Atlas optischer Erscheinungen*, Berlin–Heidelberg–New York: Springer, 1962.) (*b*) When the slit spacing equals *b*, the two slits coalesce into one (of width 2*b*) and the single-slit pattern appears—that's the first curve closest to you. The farthest curve corresponds to the two slits separated by $a = 10b$. Notice that the two-slit patterns all have their first diffraction minimum at a distance from the central maximum of Z_0. Note how the curves gradually match Fig. 10.13*b* as the slit width *b* gets smaller in comparison to the separation *a*. (Reprinted from "Graphical Representations of Fraunhofer Interference and Diffraction" *Am. J. Phys.*, 62, 6, (1994), with permission of A. B. Bartlett, University of Colorado and B. Mechtly, Northeast Missouri State University and the American Association of Physics Teachers.)

(a)

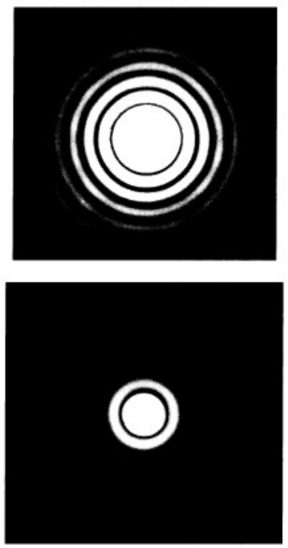
(b)



Airy rings using (a) a 0.5-mm hole diameter and (b) a 1.0-mm hole diameter. (Photo by E. H.)

(a)

(b)



(*a*) Airy rings—long exposure (1.5-mm hole diameter). (*b*) Central Airy disk—short exposure with the same aperture. (Photos by E. H.)

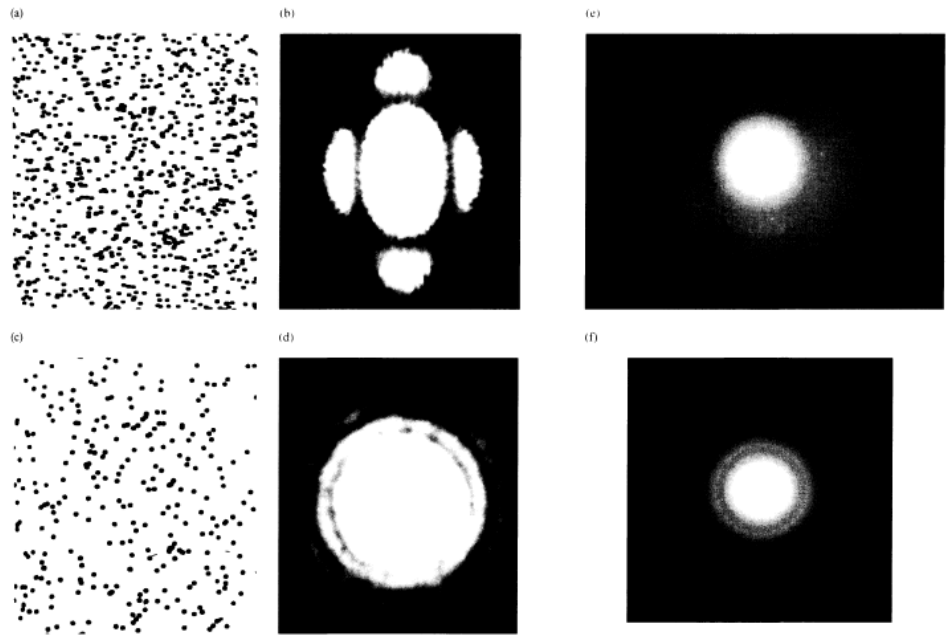
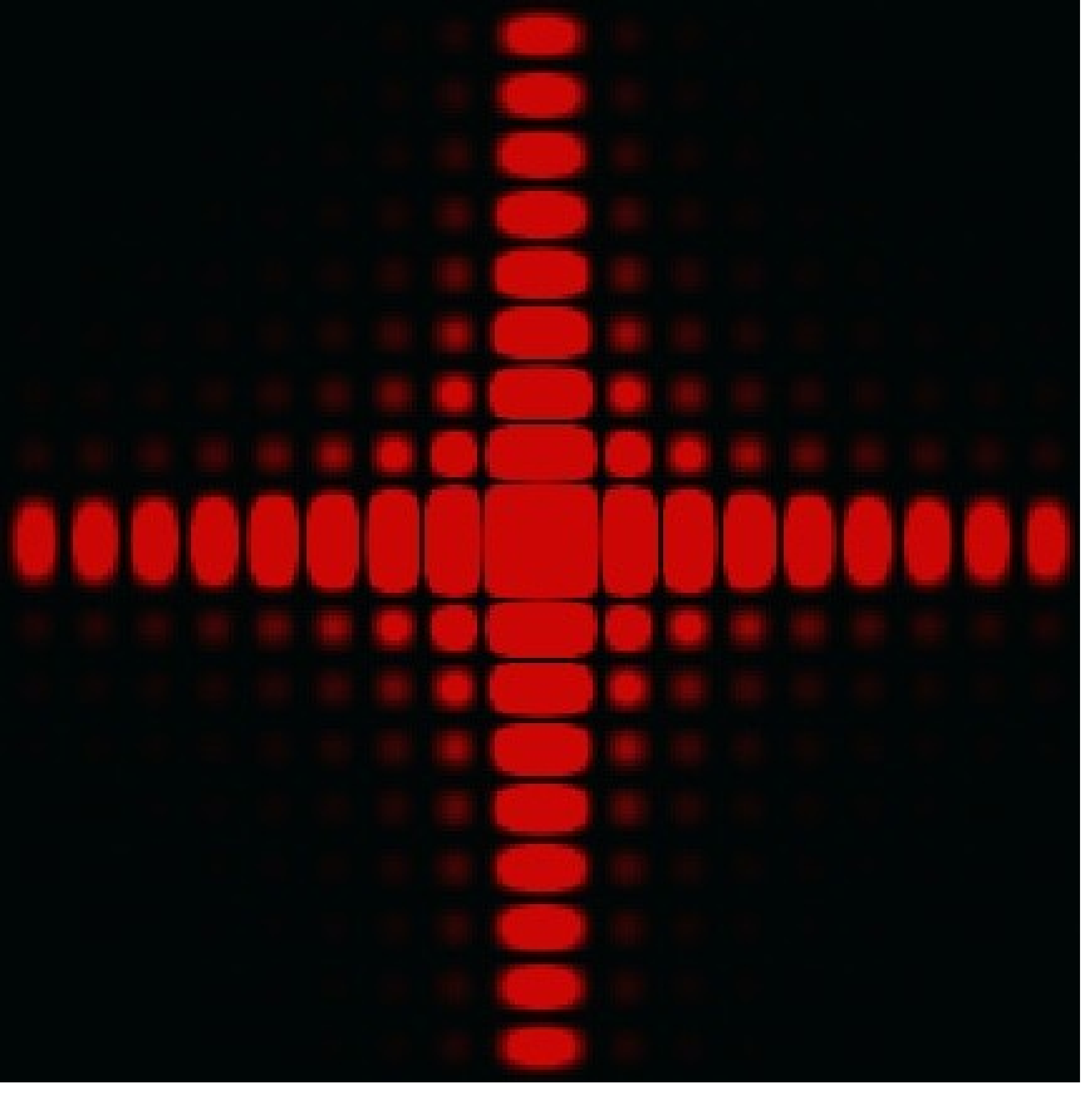
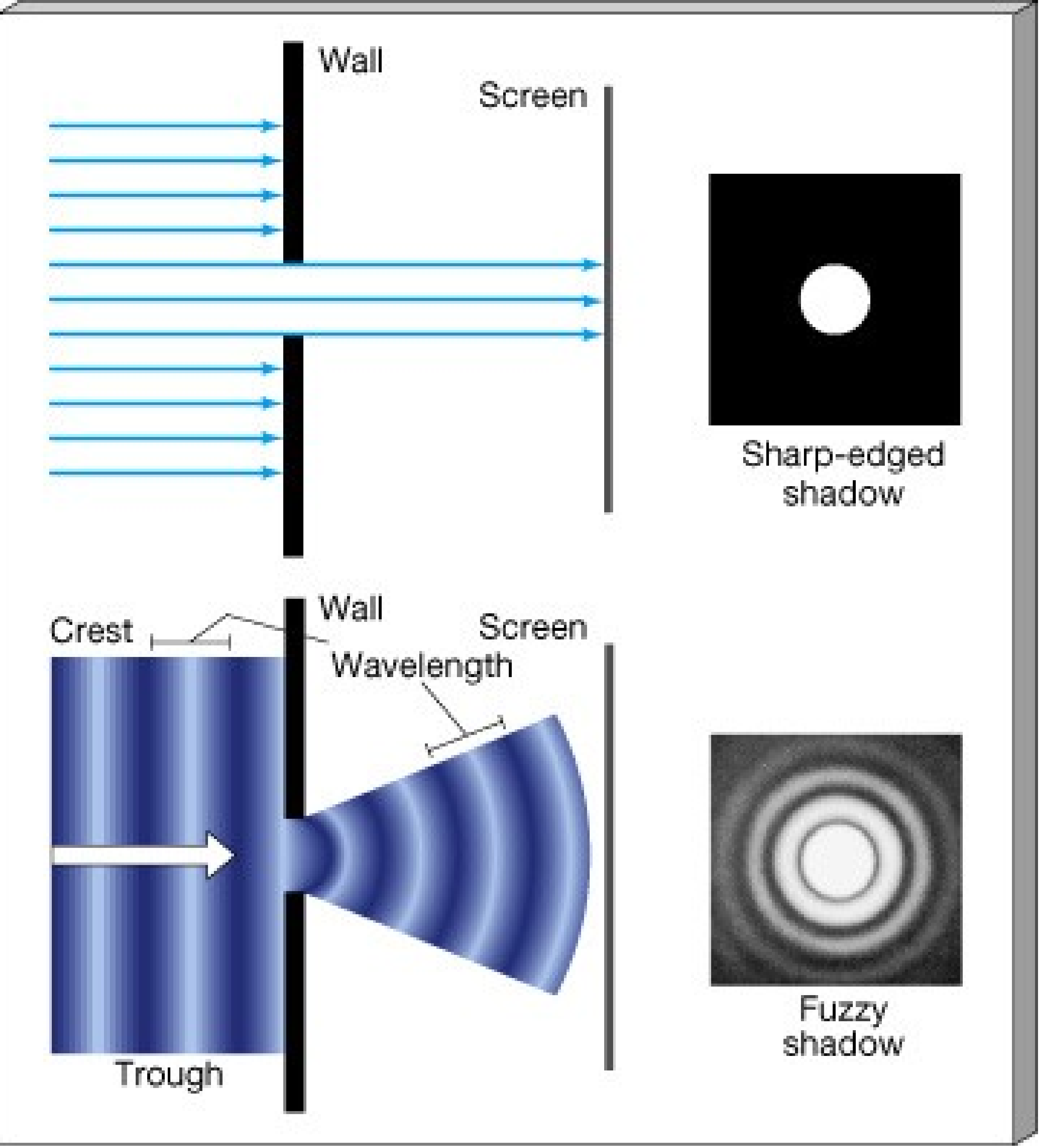


Figure 10.33 (*a*) A random array of rectangular apertures. (*b*) The resulting white-light Fraunhofer pattern. (*c*) A random array of circular apertures. (*d*) The resulting white-light Fraunhofer pattern. (Photos courtesy The Ealing Corporation and Richard B. Hoover.) (*e*) A candle flame viewed through a fogged piece of glass. The spectral colors are visible as concentric rings. (Photo by E. H.) (*f*) A similar colored ring system created by viewing a white-light point source through a glass plate covered with transparent spherical lycopodium spores. (Photo by E. H.)

Difração de uma onda de água em um tanque



Difração da luz de um laser ao passar por um orifício quadrado.


Wall
Screen
Sharp-edged shadow
Crest
Wall
Screen
Wavelength
Trough
Fuzzy shadow

O éter:

se onda se propaga como?

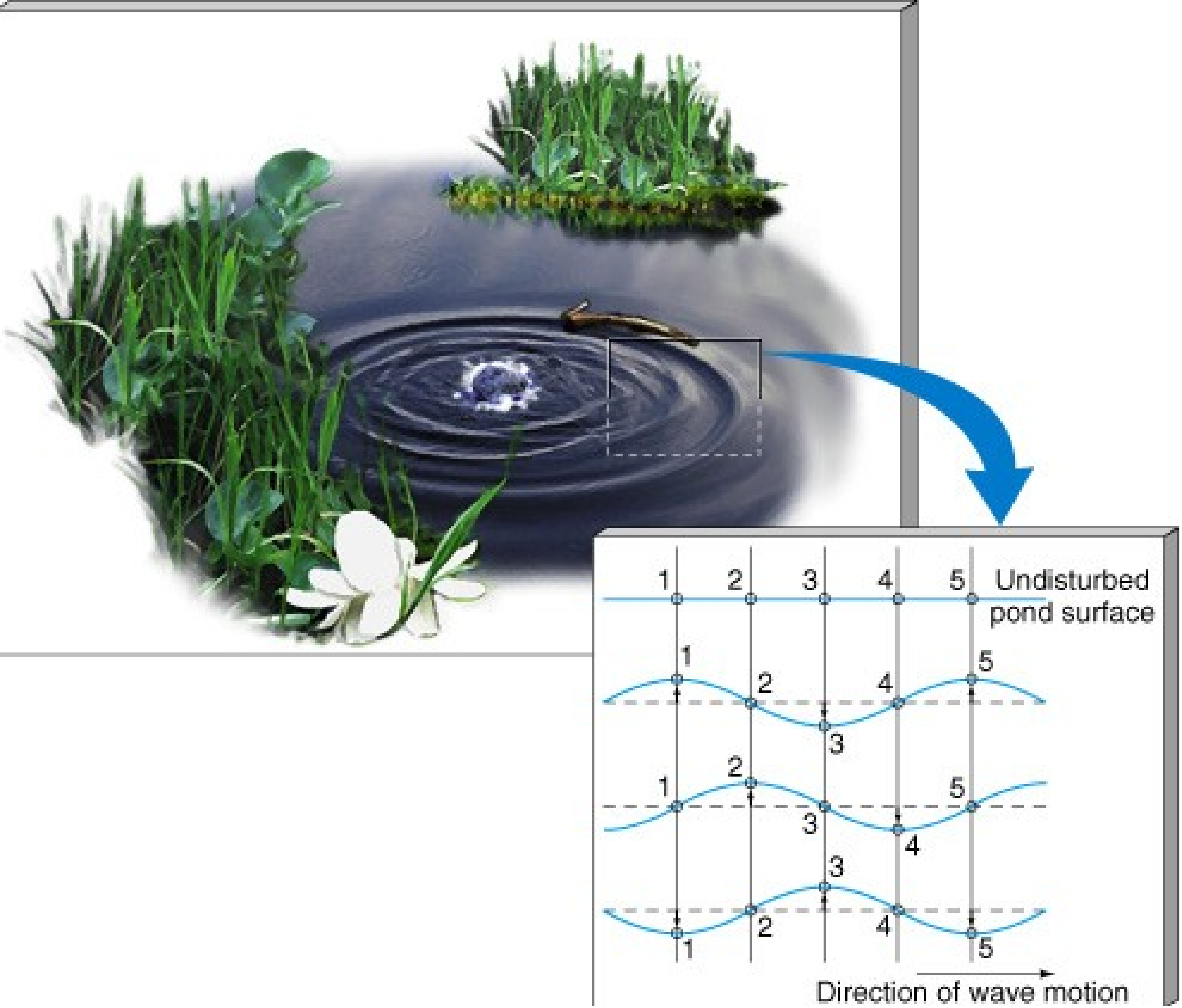
inventou-se o éter.

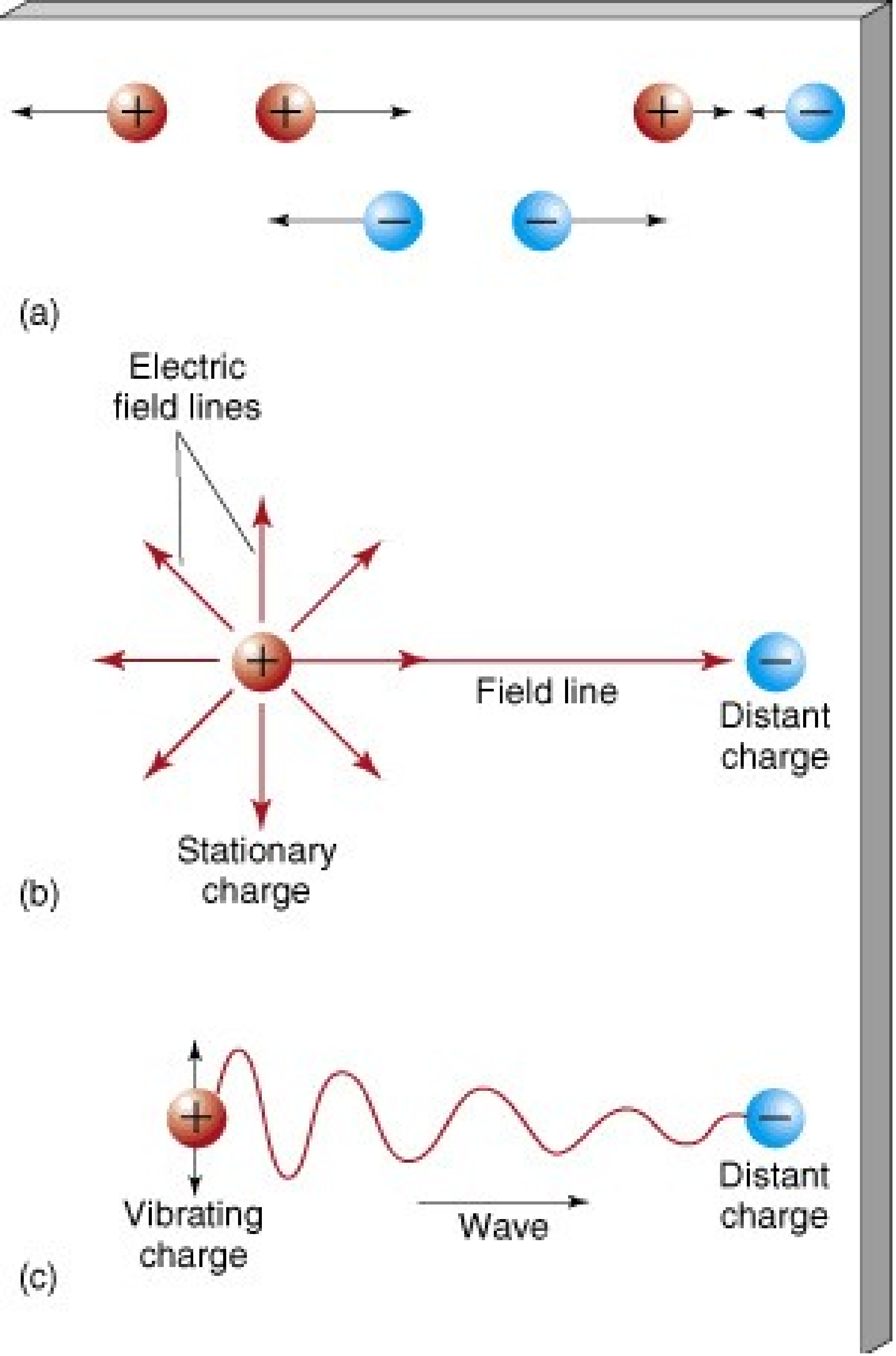
por fim se provou que o éter não existe (experiência de Michelson-Morley)

“provou-se” mais ainda: que c=constante

e por fim acabou se provando o que “não se queria”: que a luz também é uma partícula, daí começa a grande revolução da mecânica quântica.

efeito fotoelétrico:


1 2 3 4 5
Undisturbed pond surface
1 2 3 4 5
1 2 3 4 5
1 2 3 4 5
Direction of wave motion



(a)
Electric
field lines
Field line
Distant
charge
Stationary
charge
(b)
Vibrating
charge
Wave
Distant
charge
(c)

O éter:

se onda se propaga como?

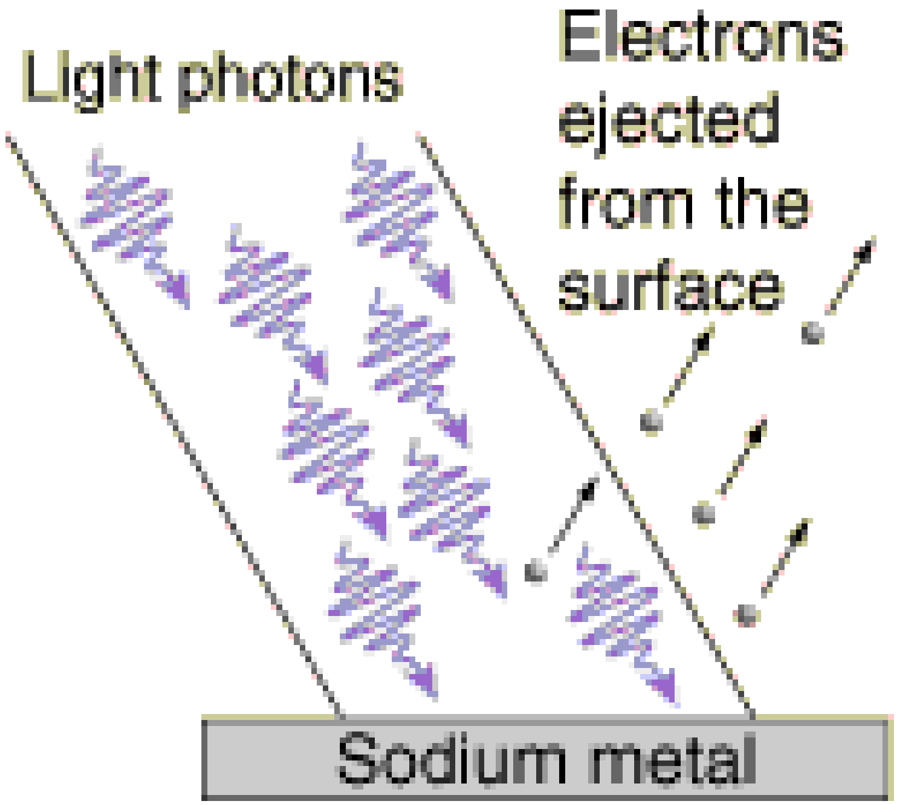
inventou-se o éter.

por fim se provou que o éter não existe (experiência de Michelson-Morley)

“provou-se” mais ainda: que c=constante

e por fim acabou se provando o que “não se queria”: que a luz também é uma partícula, daí começa a grande revolução da mecânica quântica.

efeito fotoelétrico:

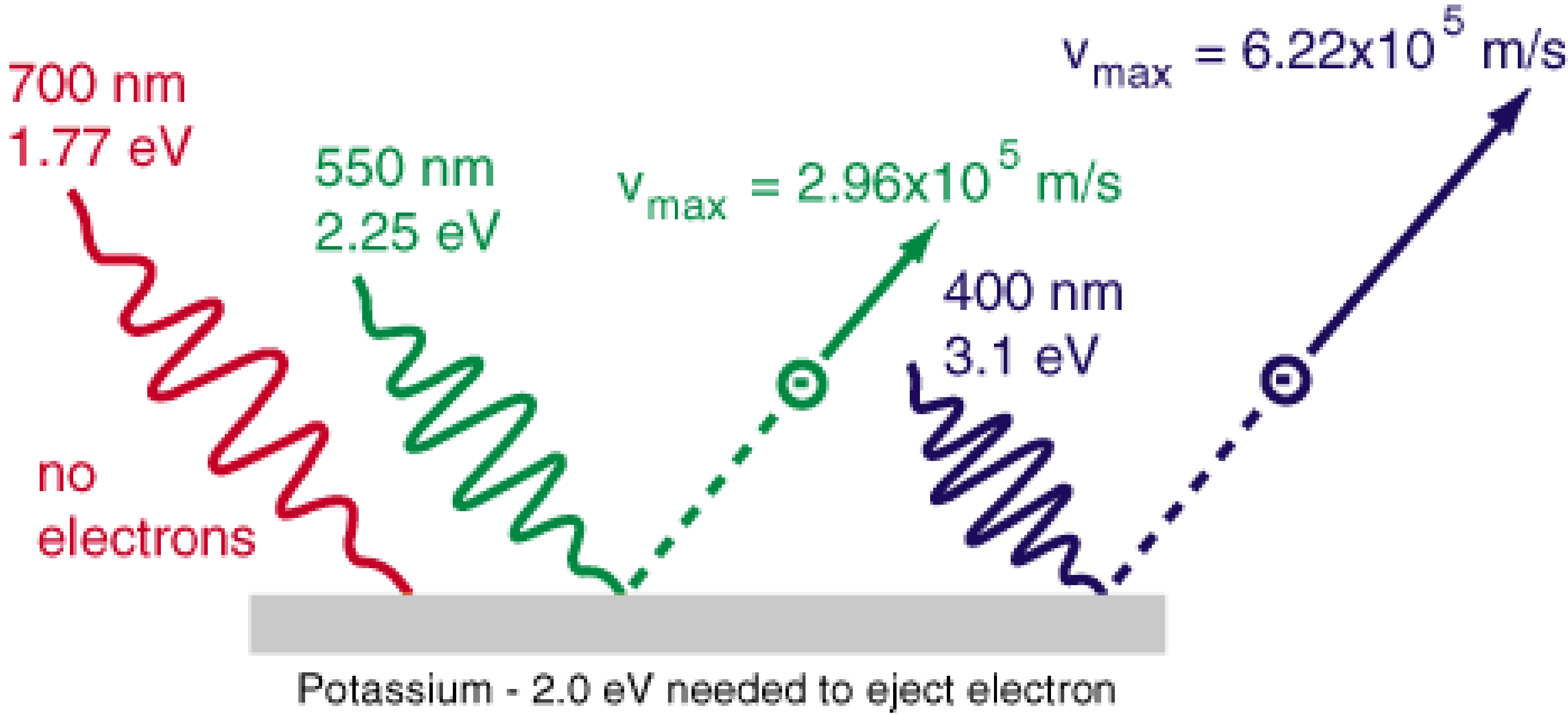


Photon energy

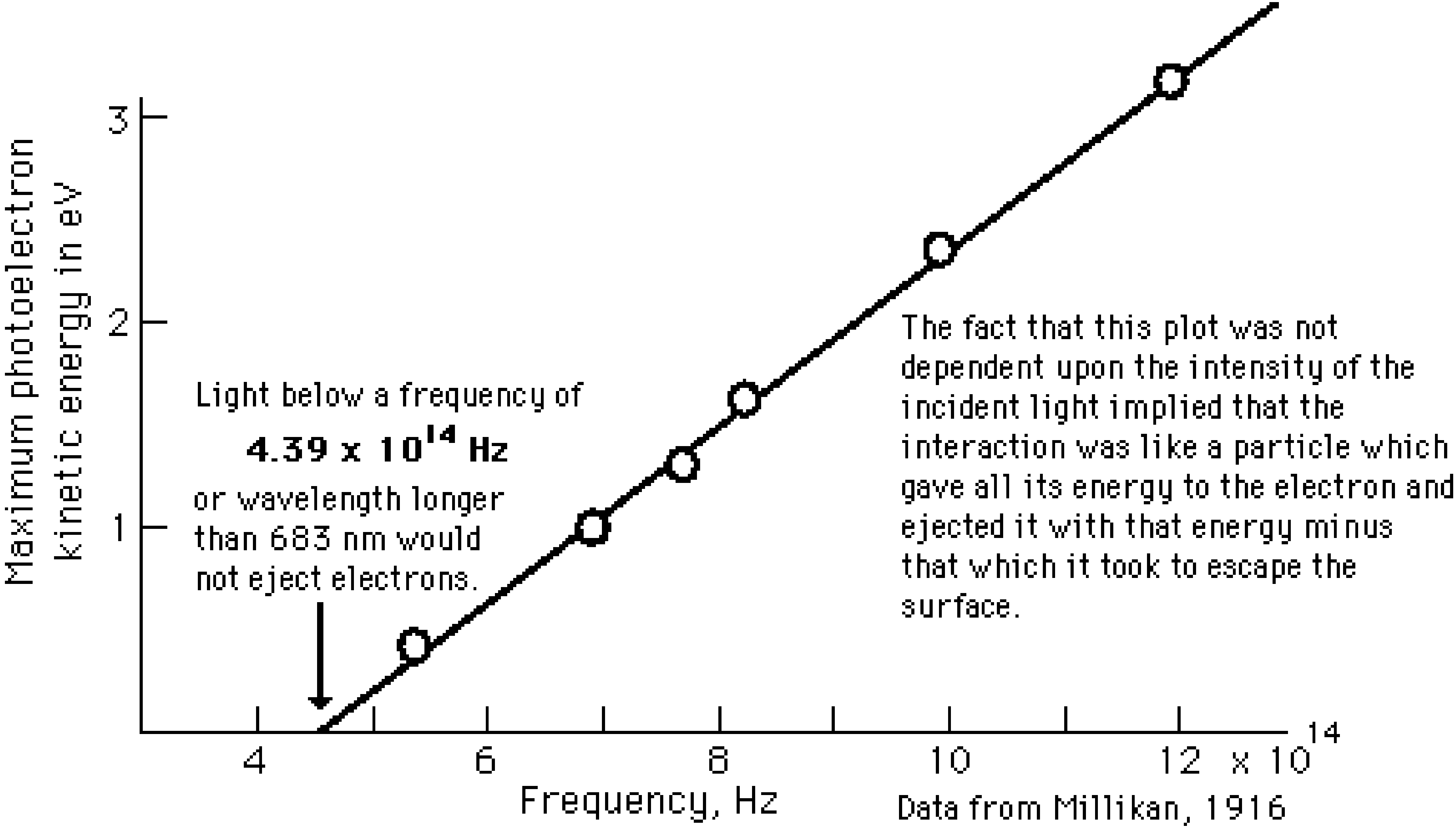
$$E = h\nu$$

explains the experiment and shows that light behaves like particles.

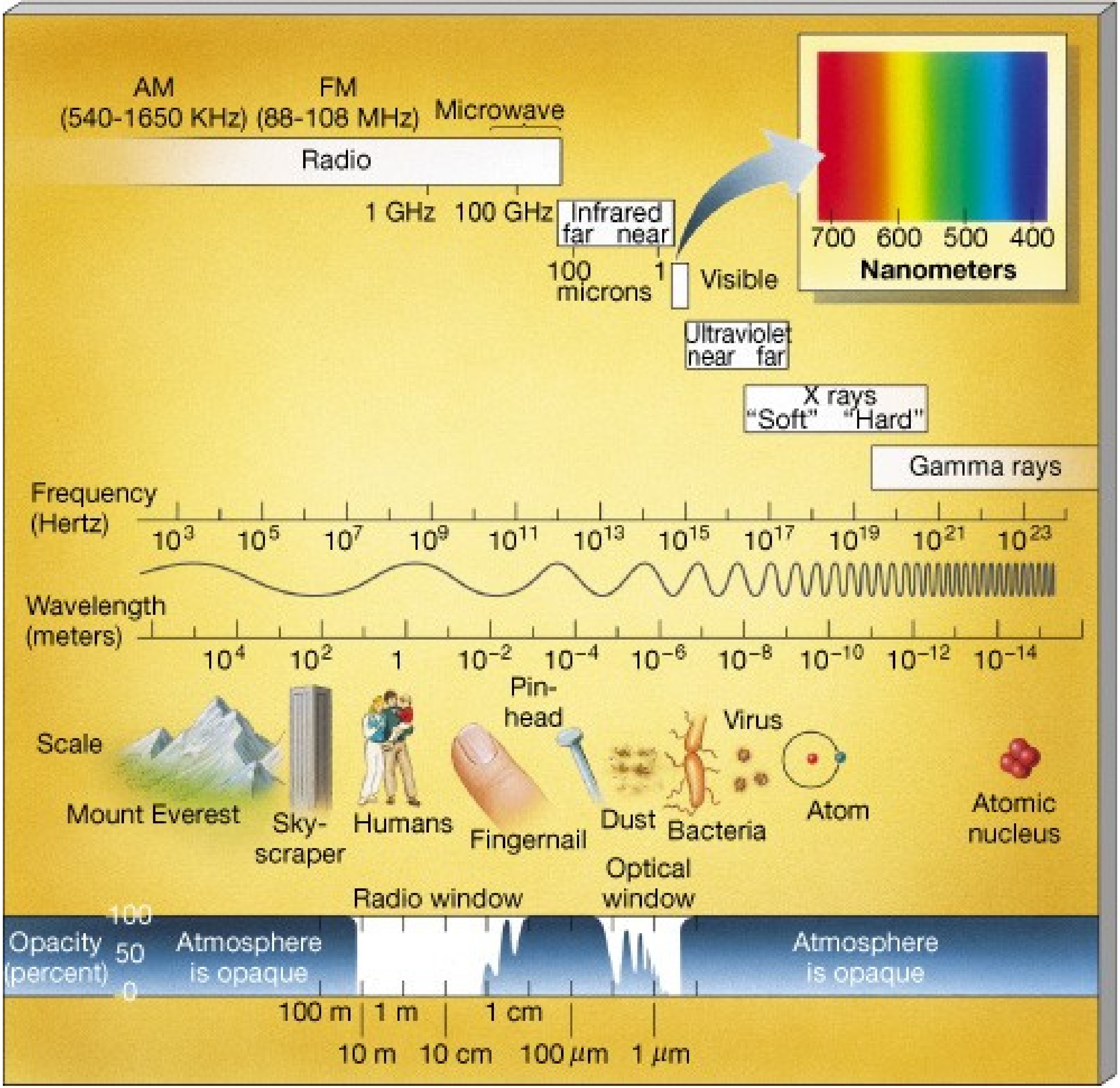
$$E_{photon} = h\nu$$



Photoelectric effect



Só há geração de elétrons quando a luz tem frequência maior que um determinado patamar



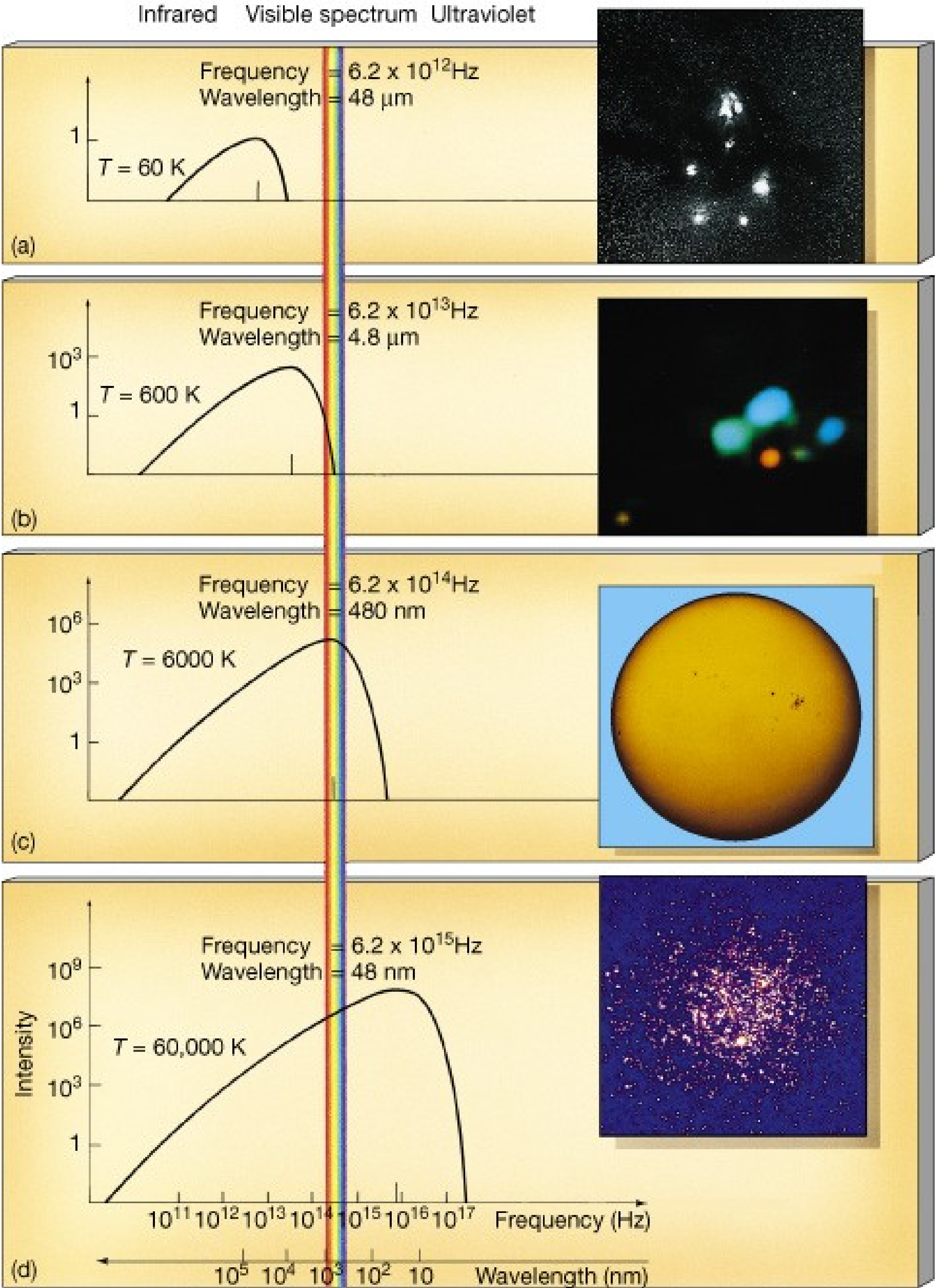
AM
(540-1650 KHz)
FM
(88-108 MHz)
Microwave
Radio
1 GHz
100 GHz
Infrared
far near
100 microns
1
Visible
700 600 500 400
Nanometers
Ultraviolet
near far
X rays
"Soft" "Hard"
Gamma rays
Frequency (Hertz)
10^3 10^5 10^7 10^9 10^{11} 10^{13} 10^{15} 10^{17} 10^{19} 10^{21} 10^{23}
Wavelength (meters)
10^4 10^2 1 10^{-2} 10^{-4} 10^{-6} 10^{-8} 10^{-10} 10^{-12} 10^{-14}
Scale
Mount Everest
Sky-scraper
Humans
Fingernail
Pin-head
Dust
Bacteria
Virus
Atom
Atomic nucleus
Radio window
Optical window
Opacity (percent)
100
50
0
Atmosphere is opaque
Atmosphere is opaque
100 m
1 m
1 cm
10 m
10 cm
100 μm
1 μm

Radiação de Corpo Negro: O Termômetro astronômico

Lei de Wien

Lei de Steffan-Boltzmann

Luminosidade total



Lei de Wien:

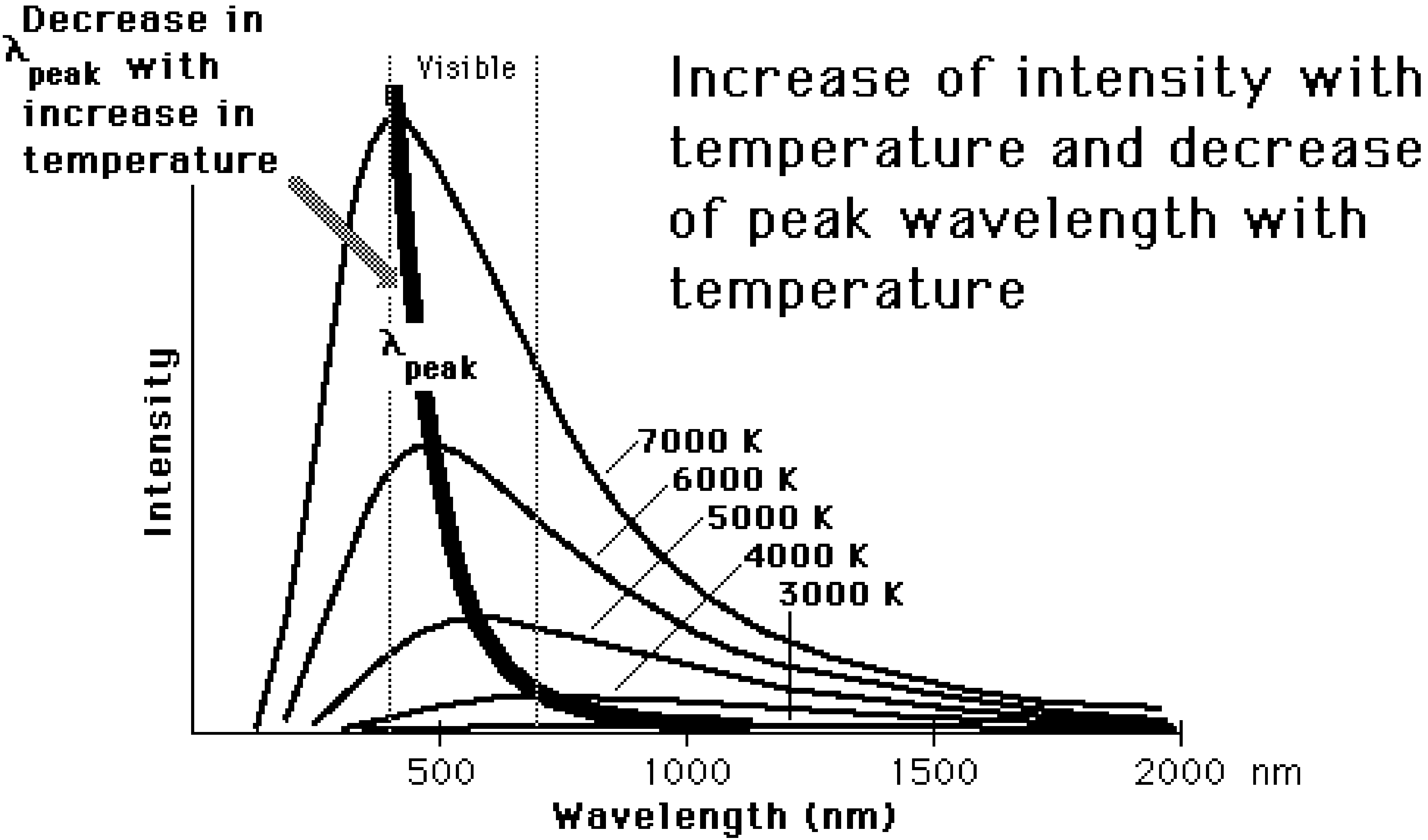
λT = 2.9x10^7 A K

Lei de Steffan Boltzmann:

F = σT^4

L = A * F

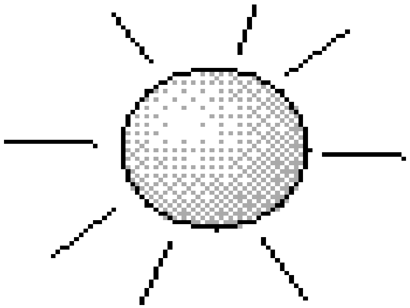
A = 4πR^2



Decrease in λ_{peak} with increase in temperature
Visible
Increase of intensity with temperature and decrease of peak wavelength with temperature
λ_{peak}
Intensity
7000 K
6000 K
5000 K
4000 K
3000 K
500
1000
1500
2000 nm
Wavelength (nm)

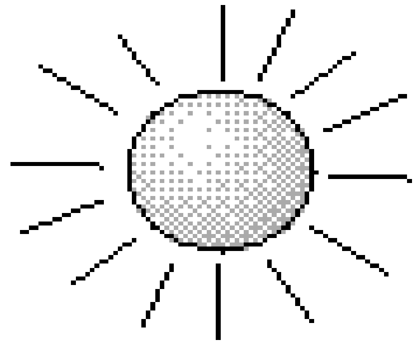
Luminosity is proportional to *fourth* power of temperature.

Sun



6000 K

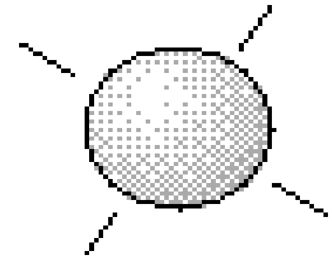
$L = 1$



12,000 K

$L = 16$

$$\left(\frac{12{,}000}{6000}\right)^4 = 2^4$$

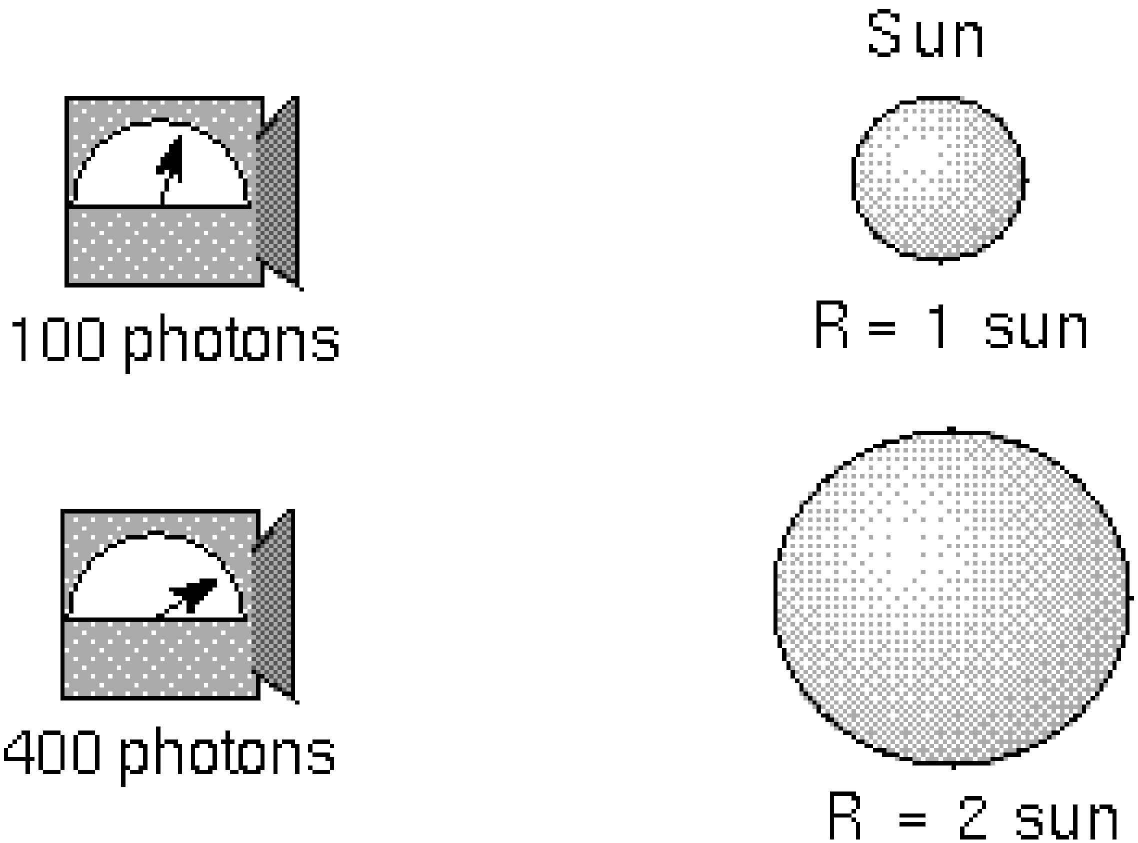


2000 K

$L = \frac{1}{81}$

$$\left(\frac{2000}{6000}\right)^4 = (1/3)^4$$

Luminosity is also proportional to the surface area.



$$\text{surface area} = 4\pi R^2$$

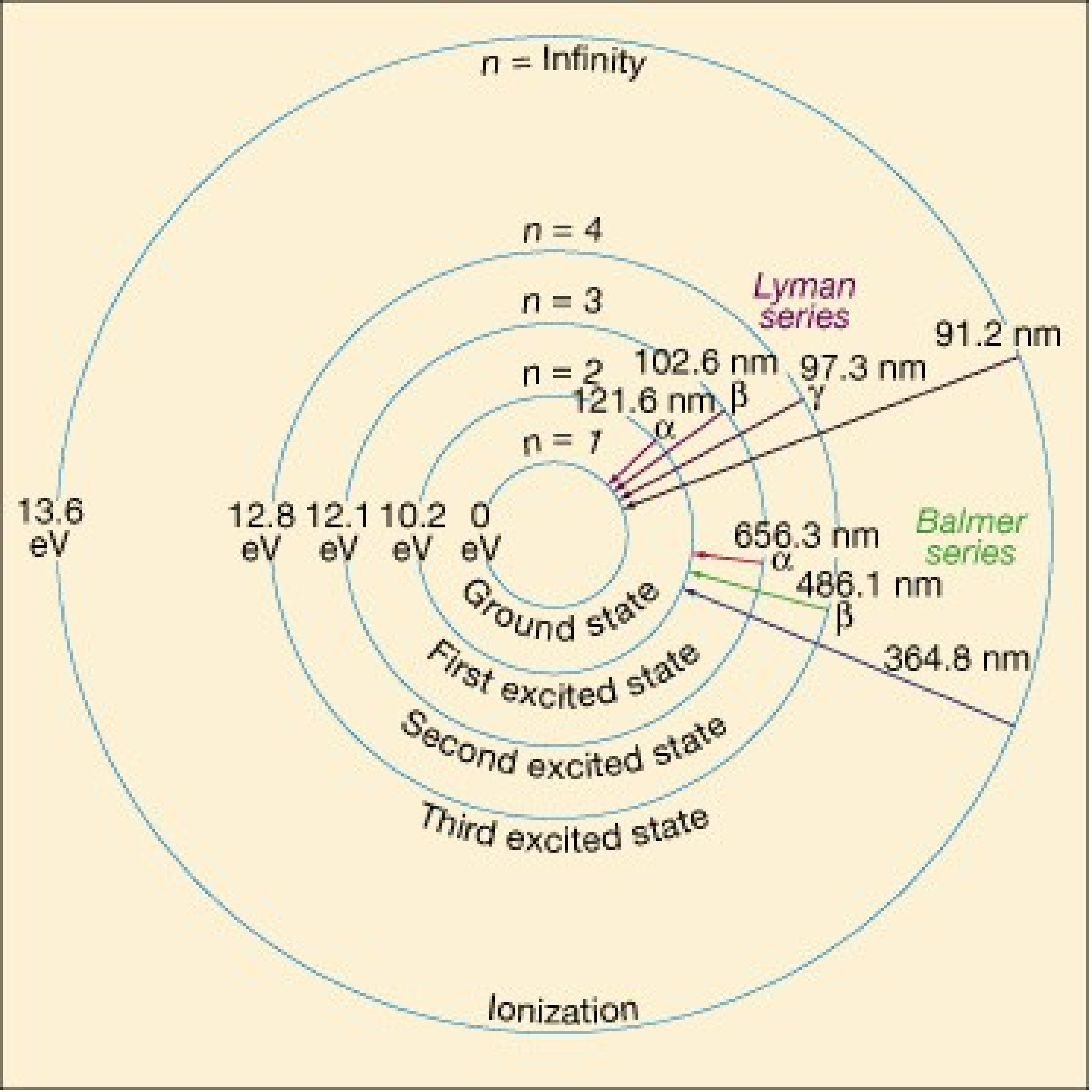
$$\frac{\text{star surface area}}{\text{Sun surface area}} = \left(\frac{2}{1}\right)^2$$

ESPECTROSCOPIA:

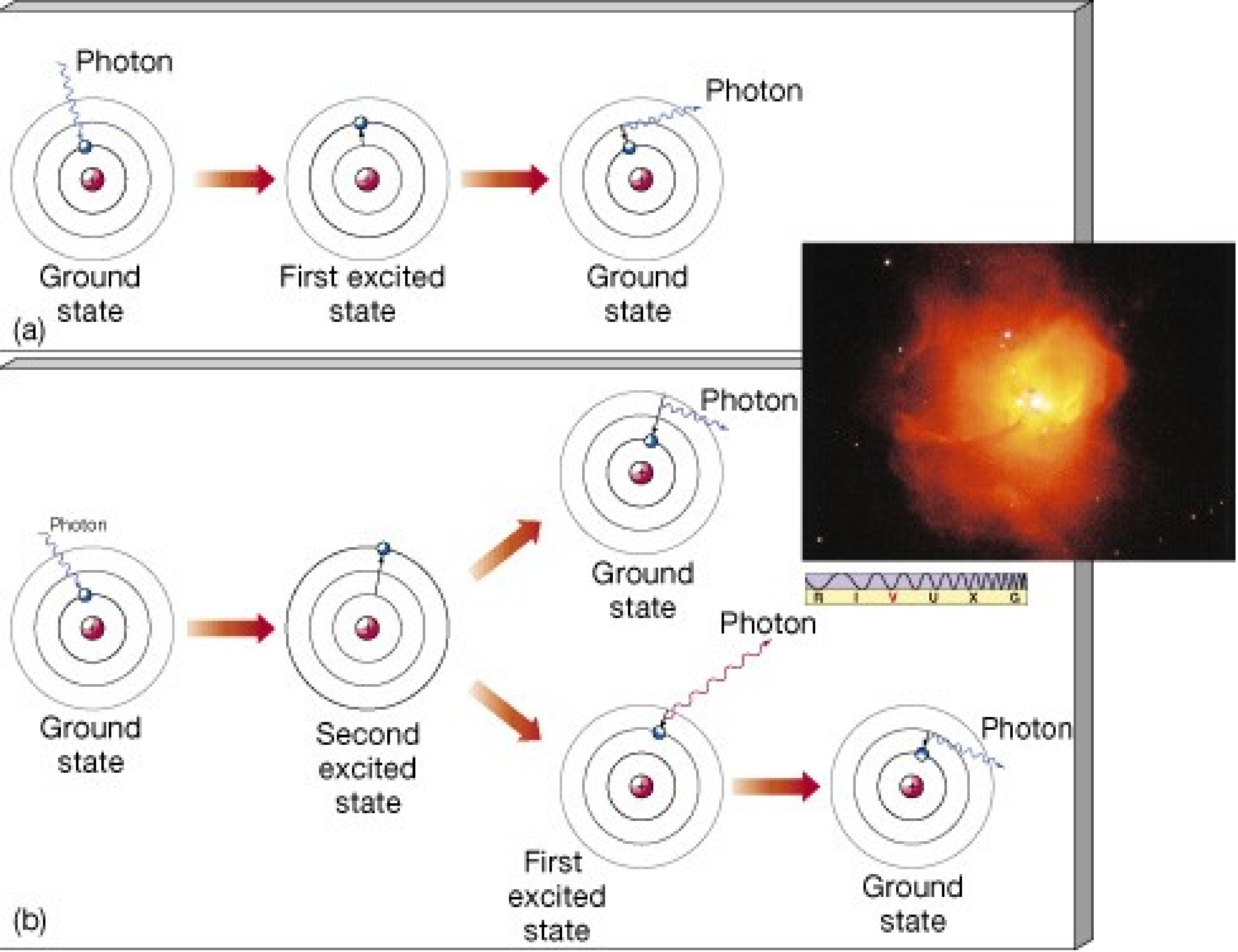
Emissão e absorção de fótons

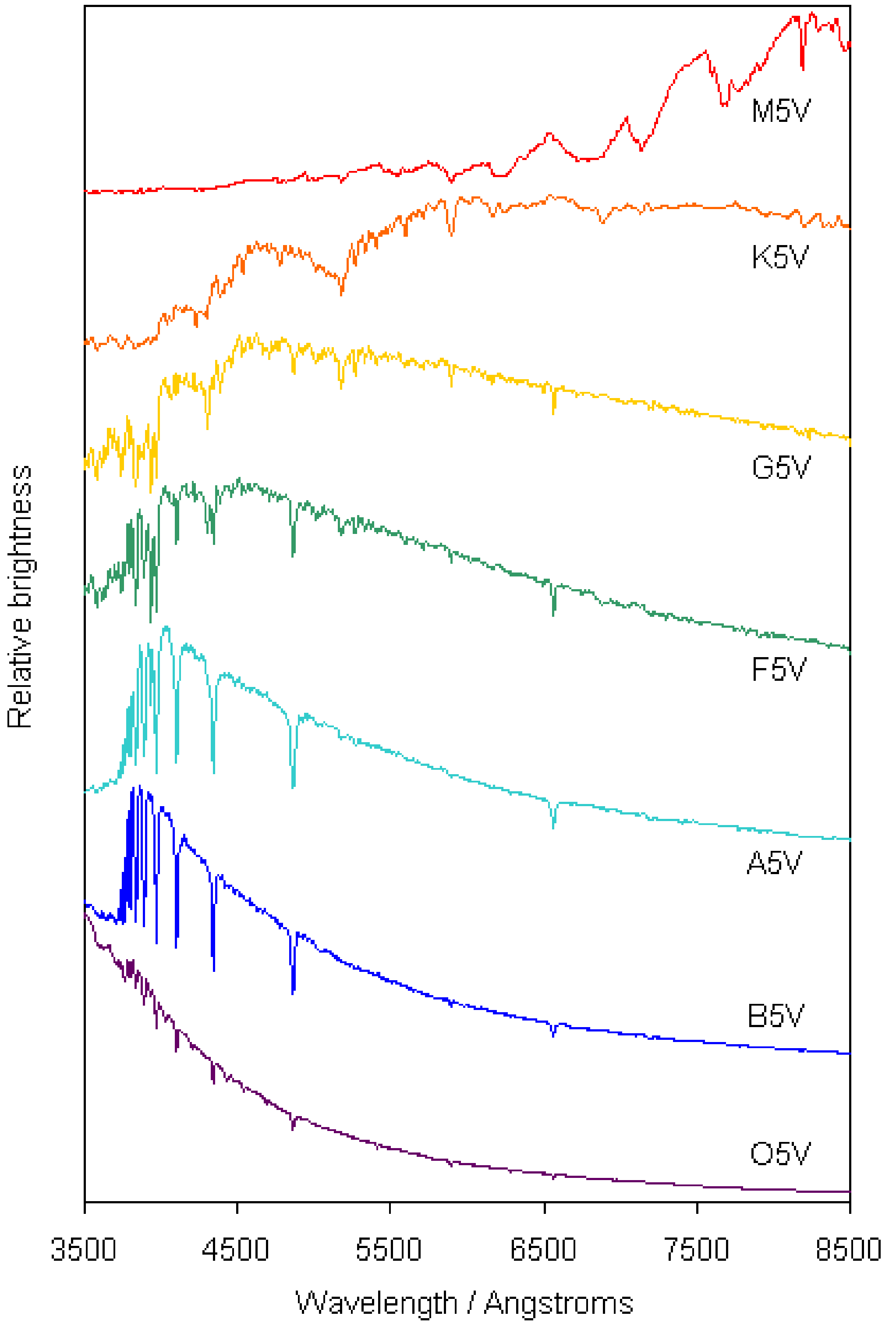
O átomo do hidrogênio

O modelo de Bohr



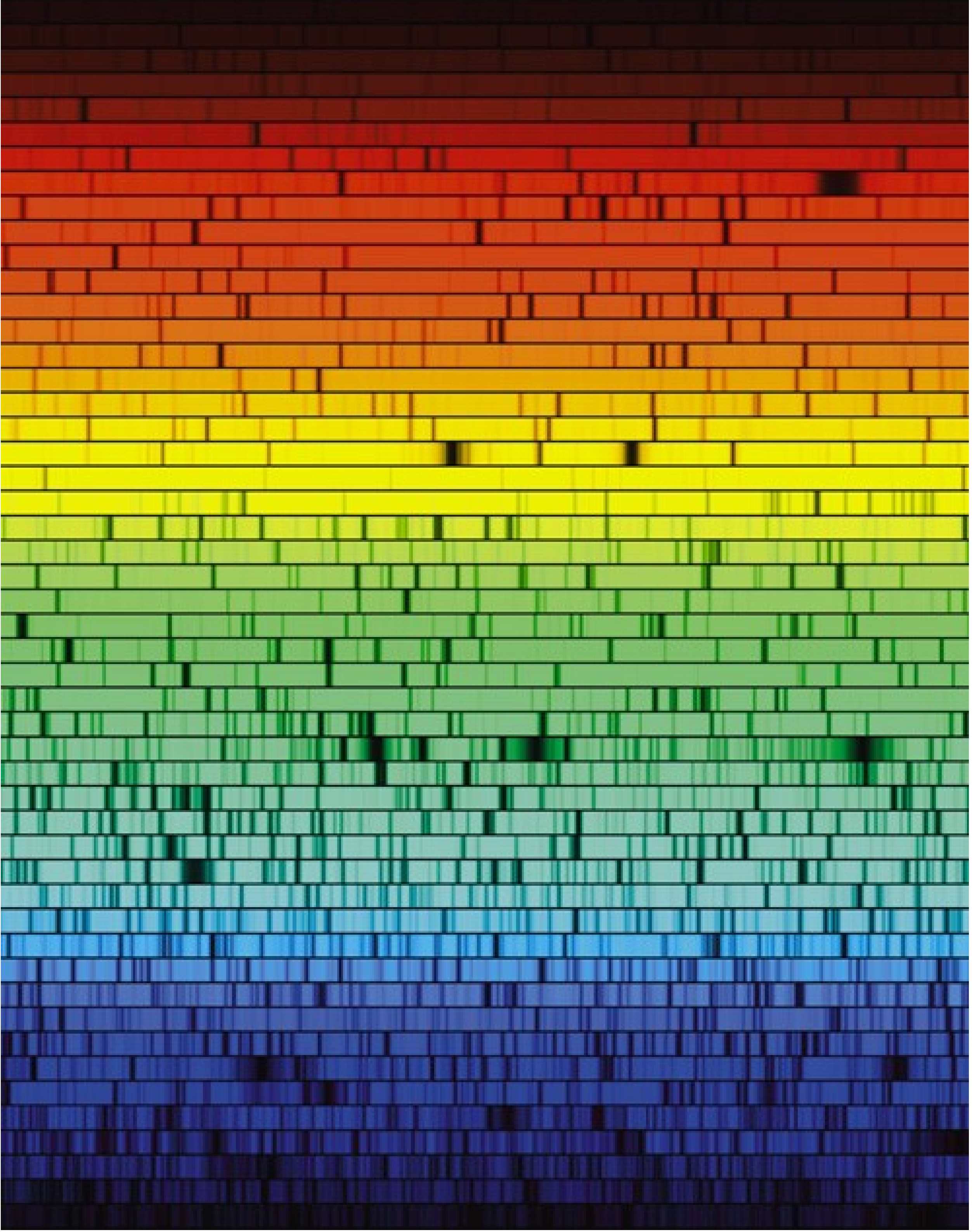
n = Infinity
n = 4
n = 3
n = 2
n = 1
Lyman series
91.2 nm
102.6 nm
β
97.3 nm
γ
121.6 nm
α
13.6 eV
12.8 eV
12.1 eV
10.2 eV
0 eV
Balmer series
656.3 nm
α
486.1 nm
β
364.8 nm
Ground state
First excited state
Second excited state
Third excited state
Ionization


Photon
Ground state
First excited state
Photon
Ground state
(a)
Photon
Ground state
Second excited state
Photon
Ground state
Photon
First excited state
Photon
Ground state
(b)
R I V U X G



Espectro de algumas estrelas “comuns”

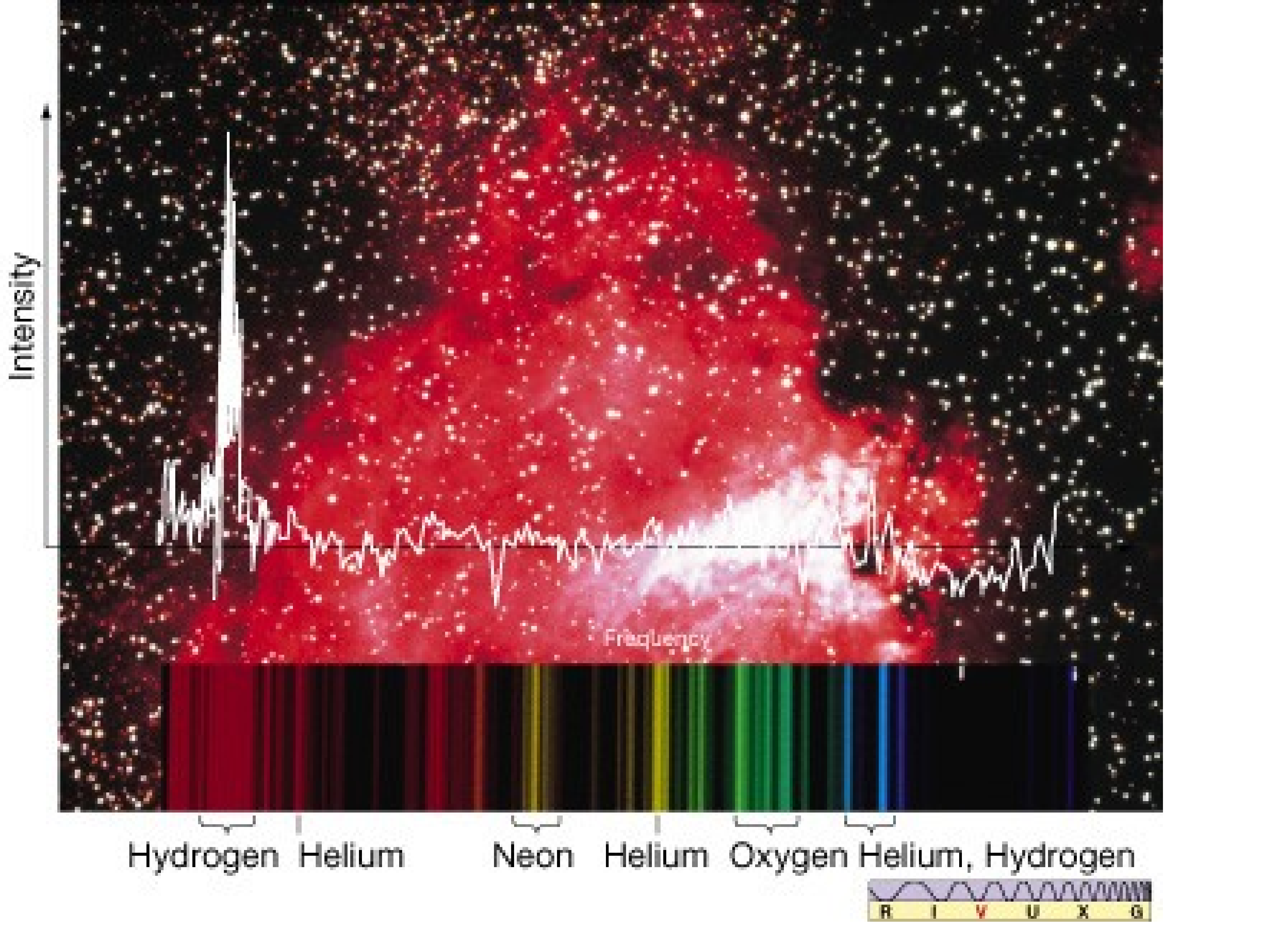
Notem para as estrelas de O5 até G5 a presença de linhas de hidrogênio.



Espectro do Sol

Esta é uma imagem do espectro solar. As cores indicam a região do espectro, e apesar de falsas indicam corretamente a posição no espectro visível.

As manchas escuras são as linhas de absorção (leis de Kirchoff logo adiante)

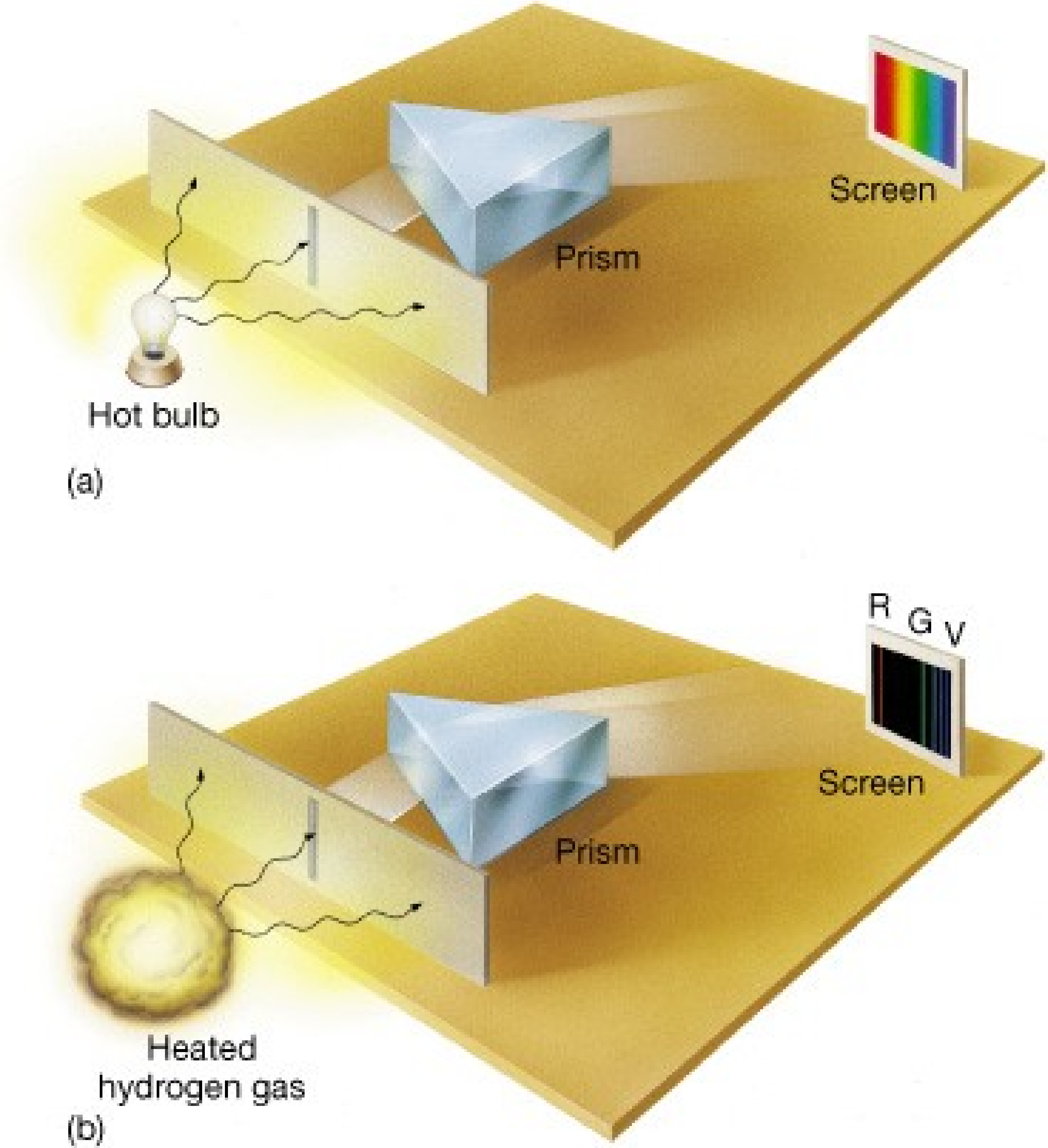

Intensity
Frequency
Hydrogen
Helium
Neon
Helium
Oxygen
Helium, Hydrogen
R I V U X G

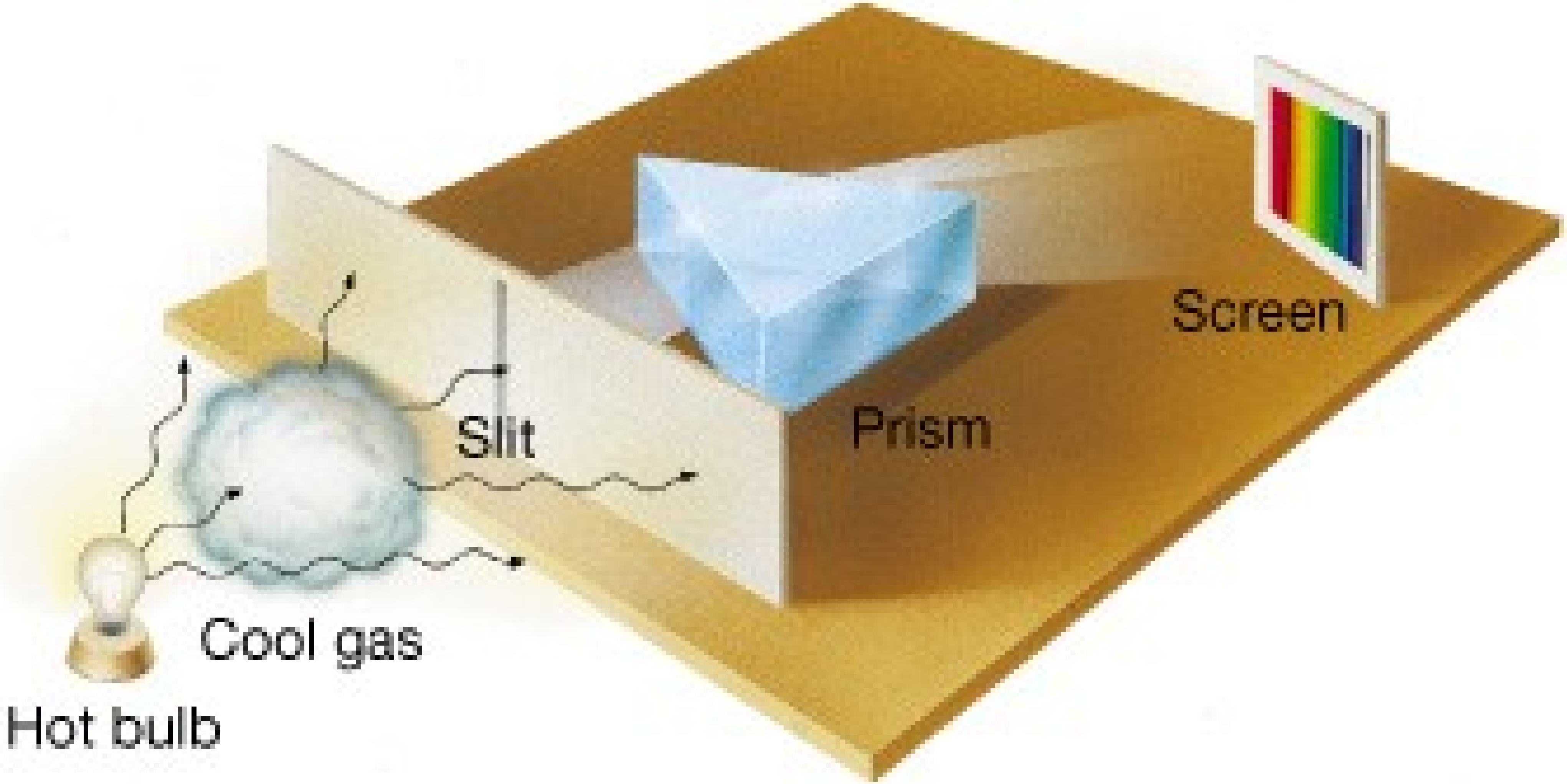
Leis de Kirchoff:

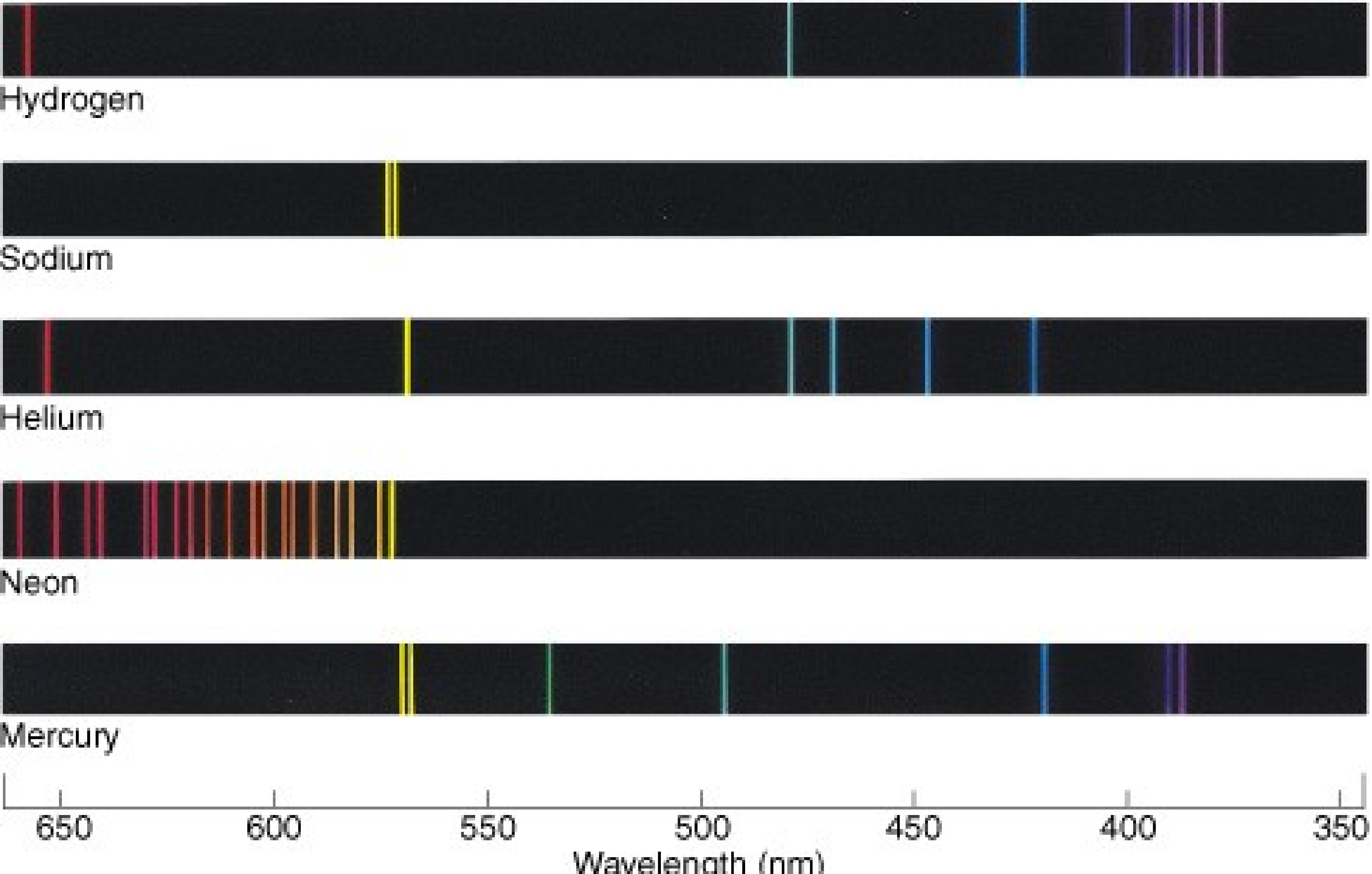
1 – contínuo – corpo denso e opaco

2 – emissão – gás fino

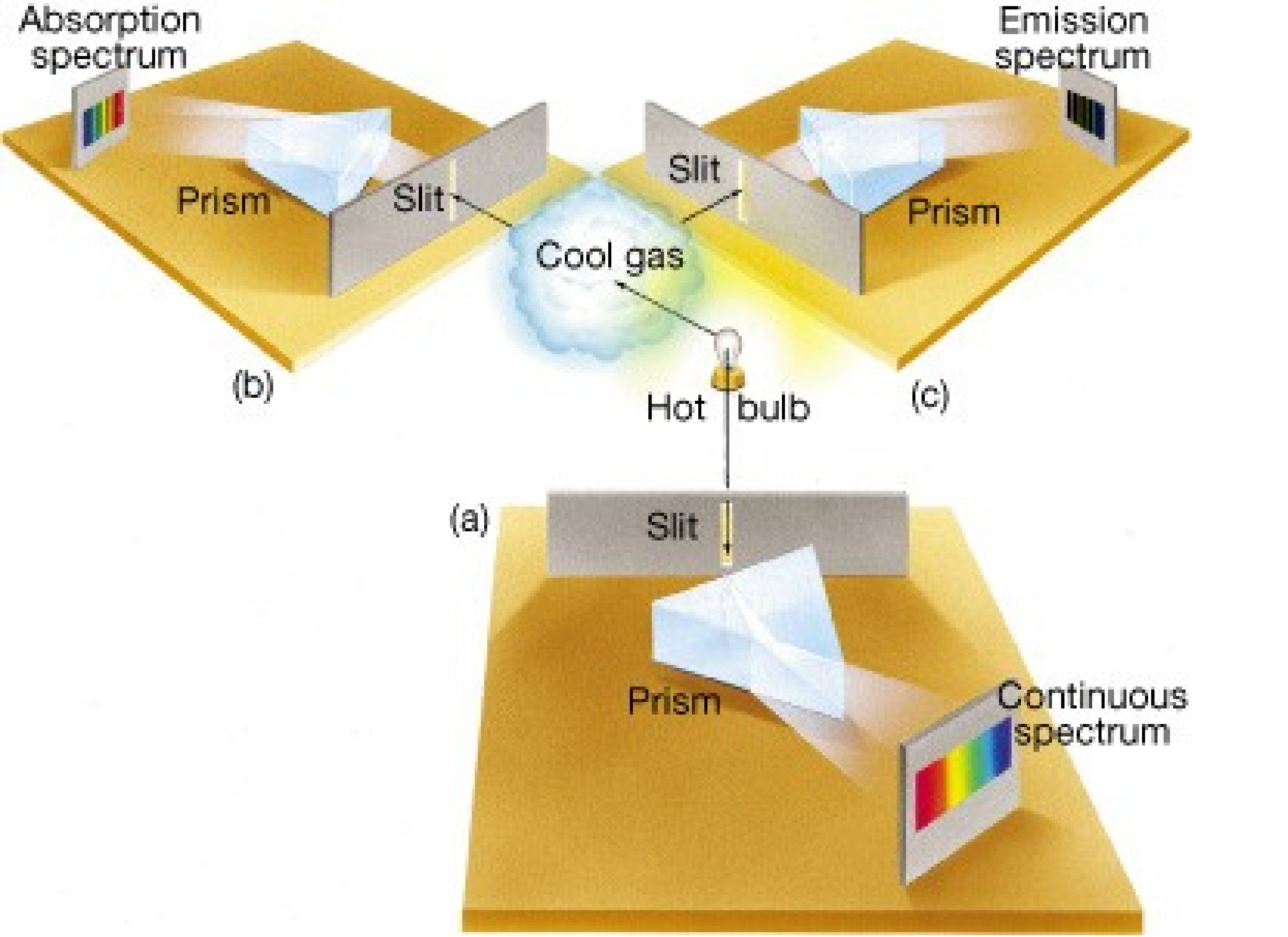
3 – absorção - gás fino iluminado por tras por algum outro objeto


Screen
Prism
Hot bulb
(a)
R
G
V
Screen
Prism
Heated
hydrogen gas
(b)

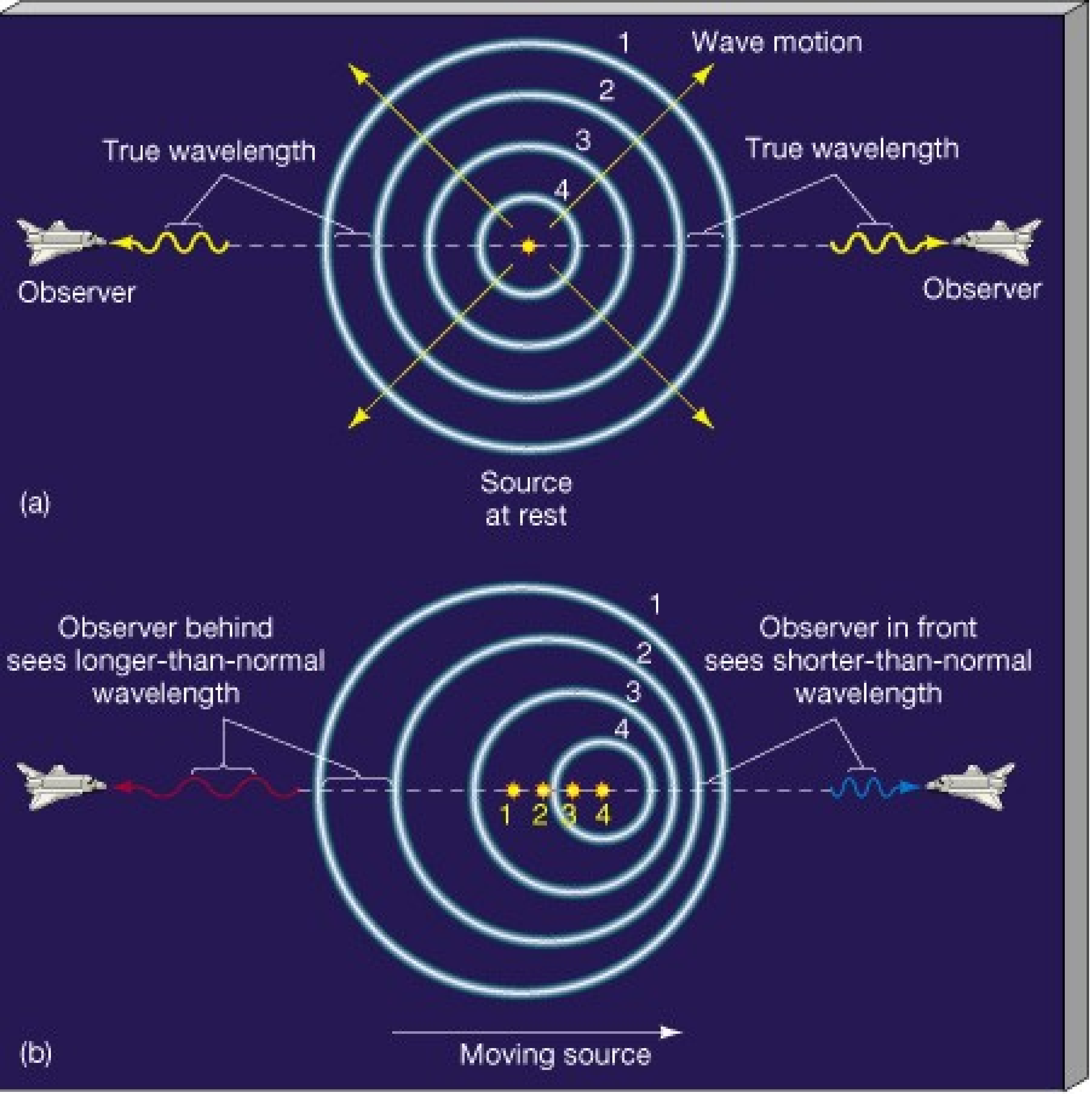

Screen
Prism
Slit
Cool gas
Hot bulb



Hydrogen
Sodium
Helium
Neon
Mercury
650
600
550
500
450
400
350
Wavelength (nm)


Absorption spectrum
Emission spectrum
Prism
Slit
Slit
Prism
Cool gas
(b)
Hot bulb
(c)
(a)
Slit
Prism
Continuous spectrum

O efeito Doppler



For waves that travel through a medium (sound, ultrasound, etc...) the relationship between observed frequency f' and emitted frequency f is given by:

$$f' = \left(\frac{v}{v \pm v_s} \right) f \,$$

where

$v \,$ is the speed of waves in the medium (in air at T degrees Celsius, this is 332 + 0.59T m/s)
$v_s \,$ is the velocity of the source (the thing emitting the sound)

For waves that travel at the speed of light, such as radio waves, the relationship between observed frequency f' and emitted frequency f is given by:
Change in frequency   Observed frequency
$$\Delta f=\frac{fv}{c}=\frac{v}{\lambda}$$

$$f'=f+\frac{fv}{c}$$

where

$f \,$ is the transmitted frequency
$v \,$ is the velocity of the transmitter relative to the receiver in meters/second: positive when moving towards one another, negative when moving away
$c \,$ is the speed of light in a vacuum $\left(3\cdot10^8\right)$ m/s
$\lambda \,$ is the wavelength of the transmitted wave subject to change

For motion along the line of sight

If the observer and the source are moving directly away from each other with velocity $v\,$, the observed frequency $f_o\,$ is different from the frequency of the source $f_e\,$ as

$$f_o = \sqrt{\frac{1-v/c}{1+v/c}}\,f_e$$

where $c\,$ is the speed of light.

The corresponding wavelengths are related by

$$\lambda_o = \sqrt{\frac{1+v/c}{1-v/c}}\,\lambda_e$$

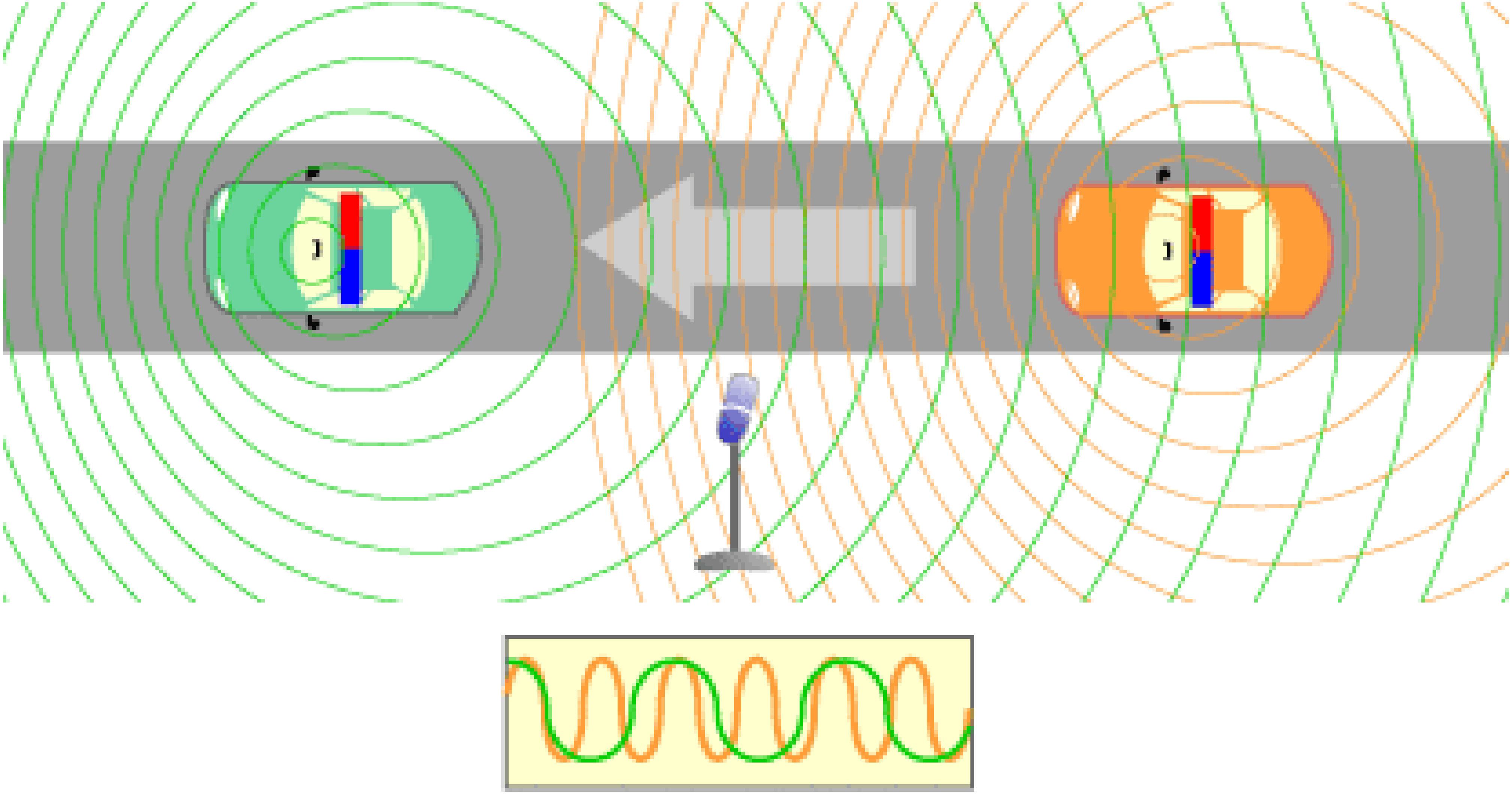
and the resulting redshift $z\,$ can be written as

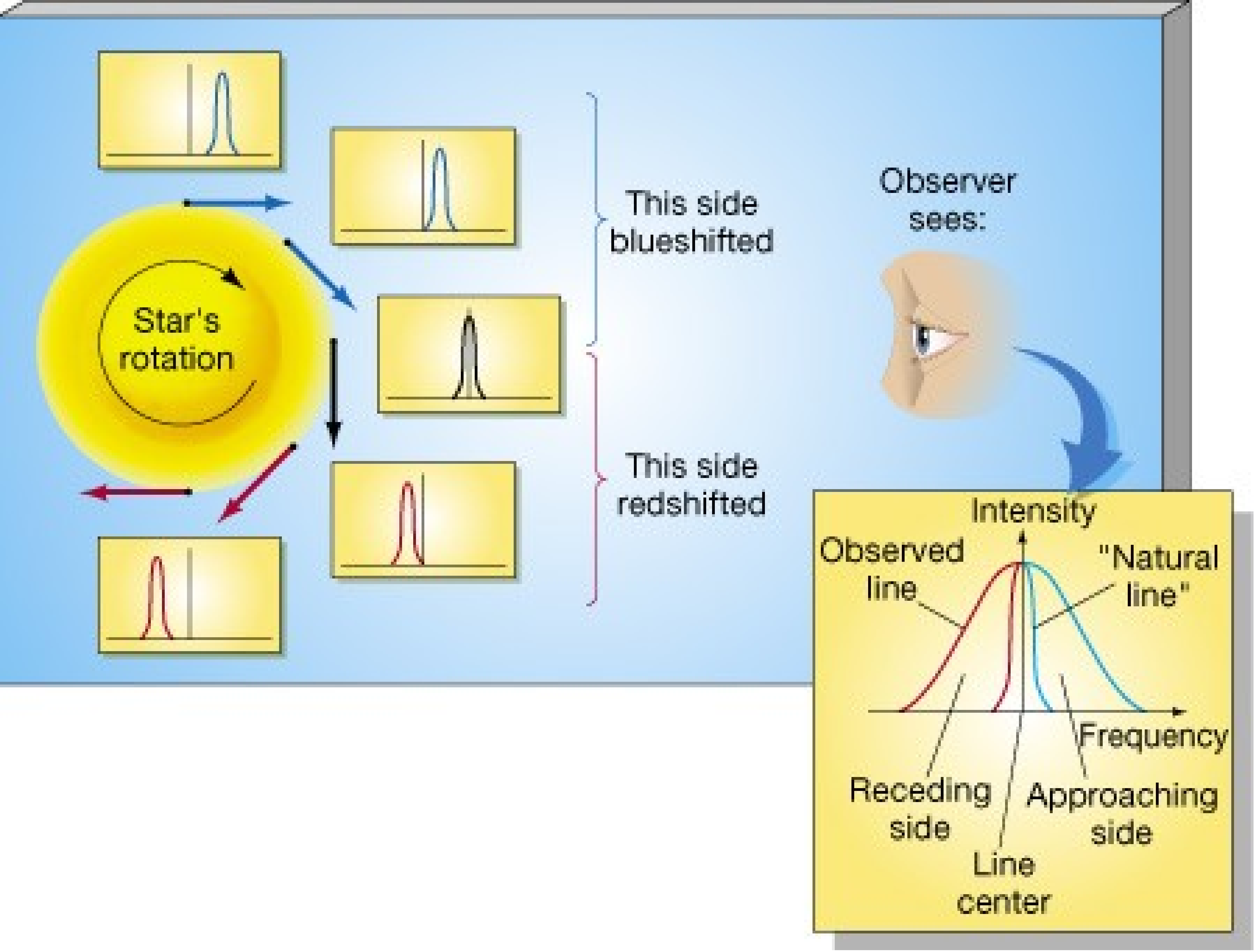
$$z + 1 = \frac{\lambda_o}{\lambda_e} = \sqrt{\frac{1+v/c}{1-v/c}}$$

In the non-relativistic limit, i.e. when $v \ll c\,$, the approximate expressions are:

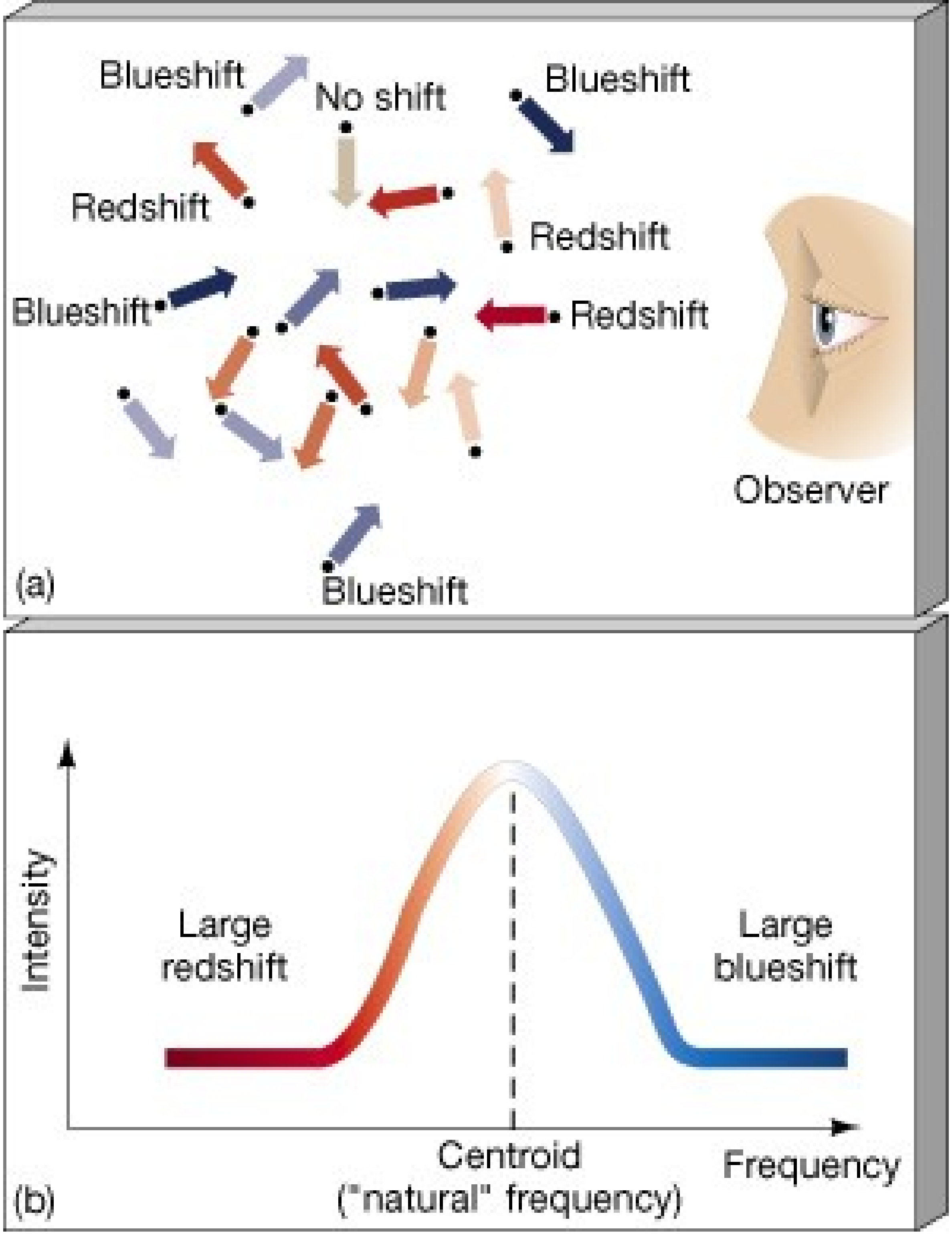
$$\frac{\Delta f}{f} \simeq -\frac{v}{c} \qquad \frac{\Delta \lambda}{\lambda} \simeq \frac{v}{c} \qquad z \simeq \frac{v}{c}$$

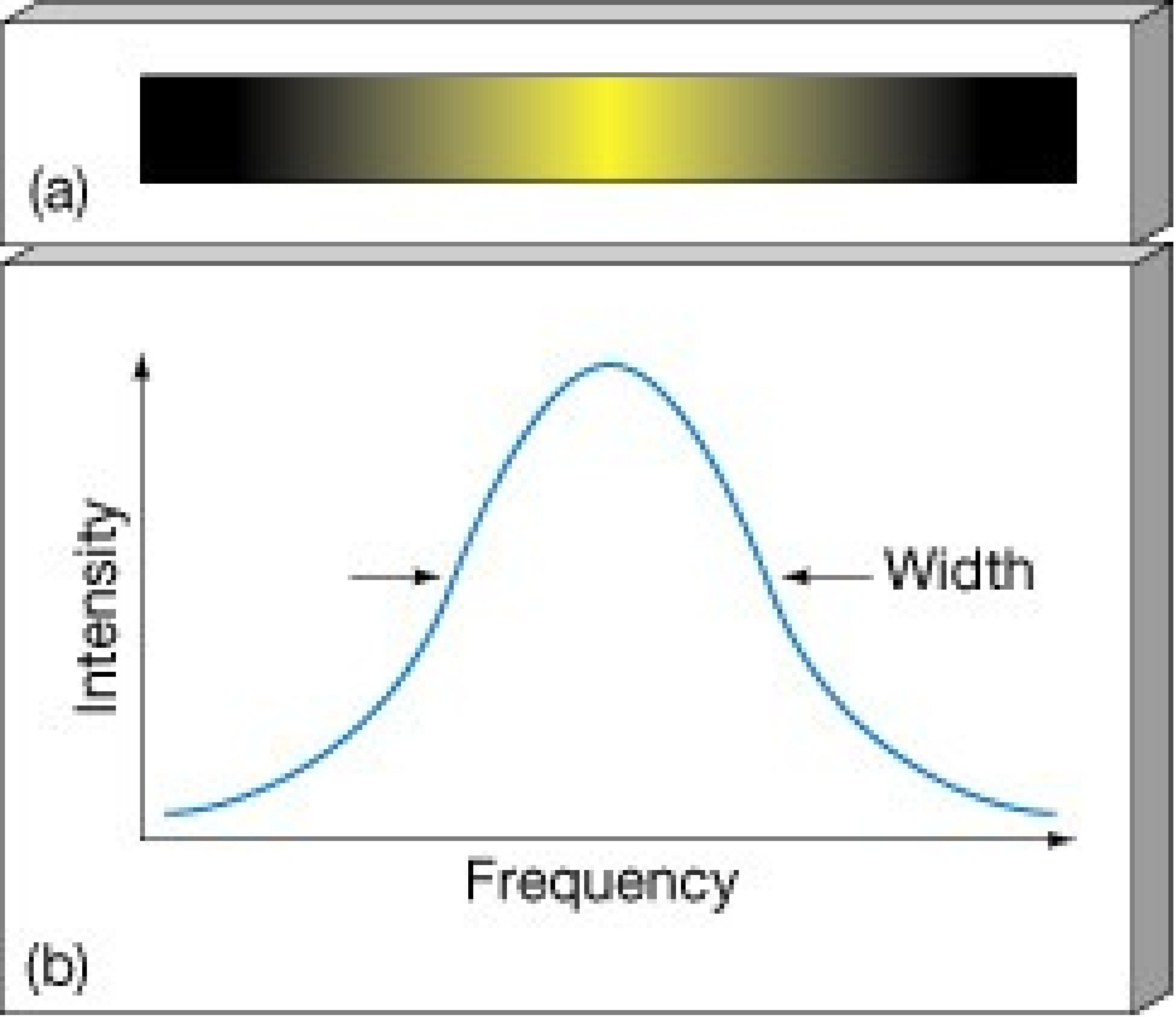
Note: In all the expressions in this section it is assumed that the observer and the source are moving away from each other. If they are moving towards each other, $v\,$ should be taken negative.





Star's rotation
This side blueshifted
This side redshifted
Observer sees:
Intensity
Observed line
"Natural line"
Frequency
Receding side
Approaching side
Line center


Blueshift
No shift
Blueshift
Redshift
Redshift
Blueshift
Redshift
Observer
(a)
Blueshift
Intensity
Large
redshift
Large
blueshift
Centroid
("natural" frequency)
Frequency
(b)



(a)
Intensity
Width
Frequency
(b)