

[TP] Red light emitted by H atoms has frequency $\nu_{\text{atom}} \sim 5 \times 10^{14}$ Hz. A typical IR frequency is $\nu_{\text{IR}} \sim 1 \times 10^{13}$ Hz. This means that, compared to the mass, m_{atom}, of what is moving in response to visible light, the moving mass in IR spectra, m_{IR}, is ...

25% 1. ~ 25 times heavier
25% 2. ~ 250 times heavier
25% 3. ~ 2,500 times heavier
25% 4. ~ 25,000 times heavier

Lecture 27 CH101 A1 (MWF 9:05 am)

Friday, November 9, 2018

Begin ch 8: Modeling atoms and their electrons

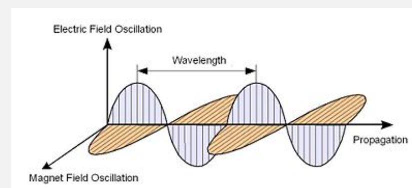
- Review: What light is and how it interacts with matter
- Natural frequencies of atoms
- Light and matter exchange energy smoothly and slowly
- Light energy is exchanged in tiny amounts called photons
- Using light-matter resonance frequencies to construct energy diagrams of matter

Next lecture: Electron waves and quantization (de Broglie) ; Hydrogen atom electron clouds

Prepare: Hydrogen atom family album, https://goo.gl/XPkcxv

Review: What light is and how it interacts with matter

Matter experiences light as an oscillating electric field



The electric field strength changes direction at frequency ν_{light}.

(The effect of the magnetic field is relatively negligible.)

The changing electric field of light tugs on matter …

Matter can respond to tugs only at "natural" frequencies of "motion" in matter

$\nu_{\text{light}} = \nu_{\text{matter}}$

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Matter responds only at its "natural" frequencies

C-O stretch $\sim 1000\ \text{cm}^{-1} = 3 \times 10^{13}/\text{s}$

ν_{stretch} = relative motion of atoms

$\nu_{\text{light}} = \nu_{\text{stretch}}$

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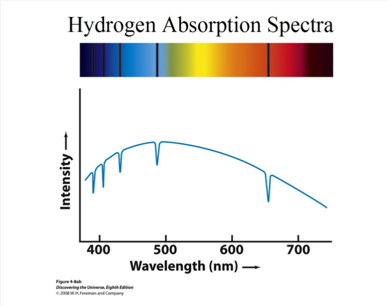
What are natural frequencies of atoms?

Here is the H atom absorption spectrum.



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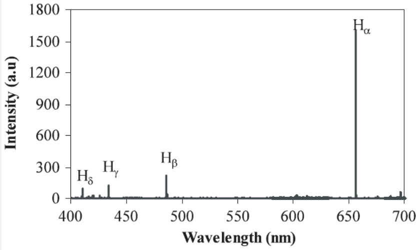
What are natural frequencies of atoms?

Here is the H atom emission spectrum.



There are four "peaks", at 410 nm, 434 nm, 486 nm, and 656 nm.

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What are natural frequencies of atoms?

There are four “lines”, at 410 nm, 434 nm, 486 nm, and 656 nm.

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What are natural frequencies of atoms?

Since light interacts with matter when $\nu_{\mathrm{light}} = \nu_{\mathrm{matter}}$, these lines mean …

there is motion in the atom

at the frequencies, ν_{atom}, corresponding to these lines.

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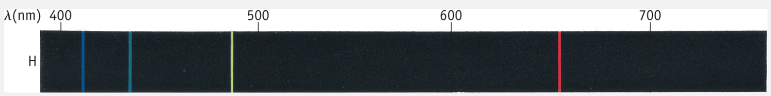
What are natural frequencies of atoms?



What is the frequency of motion in the H atom corresponding to the 656 nm line?

$$\nu_{\mathrm{atom}} = \frac{c}{\lambda_{\mathrm{atom}}} = \frac{2.998 \times 10^{8}\,\mathrm{m/s}}{656\ \mathrm{nm}} = 4.57 \times 10^{14}\mathrm{s} \sim 5 \times 10^{14}\mathrm{s}$$

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What are natural frequencies of atoms?

The red light emitted has frequency $\nu_{\mathrm{atom}} \sim 5 \times 10^{14}$ Hz.

For IR, at typical frequency due to the oscillation of light atoms is $\nu_{\mathrm{IR}} \sim 1 \times 10^{13}$ Hz.

Since forces in IR and in atoms are both electrical, force constants are similar.

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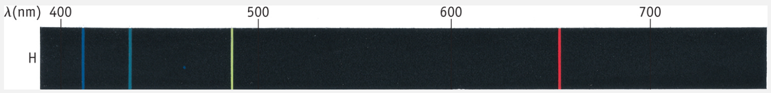
What are natural frequencies of atoms?



The red light emitted has frequency $\nu_{\text{atom}} \sim 5 \times 10^{14}$ Hz.

For IR, at typical frequency due to the oscillation of light atoms is $\nu_{\text{IR}} \sim 1 \times 10^{13}$ Hz.

Since force constants are similar, the frequency difference must be due to mass difference.

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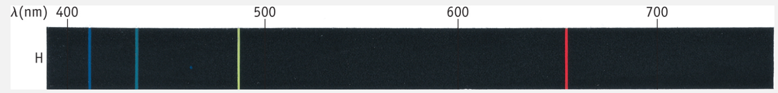
What are natural frequencies of atoms?



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For IR, at typical frequency due to the oscillation of light atoms is $\nu_{\text{IR}} \sim 1 \times 10^{13}$ Hz.

Estimate the ratio of the mass of what is moving in H atom, m_{atom}, relative to the mass moving at $\sim 1 \times 10^{13}$ Hz, m_{IR}.

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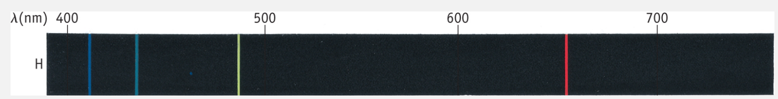
What are natural frequencies of atoms?



Estimate the ratio of the mass of what is moving in H atom, m_{atom}, relative to the mass moving at $\sim 1 \times 10^{13}$ Hz, m_{IR}.

$$\nu_{\text{atom}}/\nu_{\text{IR}} \sim 50 = \sqrt{\frac{m_{\text{IR}}}{m_{\text{atom}}}}$$

$m_{\text{IR}}/m_{\text{atom}} \sim 50^2$ so m_{IR} is ~ 2500 times heavier than m_{atom}.

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What are natural frequencies of atoms?

$m_{IR}/m_{atom} \sim 50^2$ so m_{IR} is ~ 2500 times heavier than m_{atom}.

So, what is it that is moving in the atom in response to visible light that is so much lighter that the atoms themselves moving in response to IR light?

Motion of electron clouds accounts for how atoms interact with light:

$$\nu_{light} = \nu_{cloud}$$

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Light and matter exchange energy smoothly and slowly

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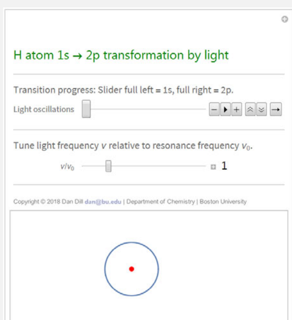
Resonant tugs by light on an electron cloud

http://goo.gl/Ac4HGM



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Resonant tugs by light on an electron cloud

Each oscillation takes about $1/\nu \sim 10^{-14}$ seconds (in visible region)

About 100,000 oscillations are required to complete the transformation

So about

$$10^{-14}\text{s/osc} \times 10^{5}\text{osc} = 10^{-9}\text{s}$$

are required to transform the 1s cloud into the 2p cloud.

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Resonant tugs by light on an electron cloud

What does the animation show?

Response requires resonance.

Change is smooth

“Transition” takes time

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Light energy is exchanged in tiny amounts called photons

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Total energy exchanged is $h\nu_{\text{light}} = hc/\lambda_{\text{light}}$

This amount energy is called a photon.

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$\Delta E_{\text{light}} + \Delta E_{\text{atom}} = 0$

Photon energy units are exchanged between light and atoms,

$\Delta E_{\text{light}} + \Delta E_{\text{atom}} = 0$, that is $\Delta E_{\text{light}} = -\Delta E_{\text{atom}}$

Emission of light:

Light gains (a photon of) energy, $\Delta E_{\text{light}} = hc/\lambda$

Atom electron cloud loses energy, $\Delta E_{\text{atom}} = -hc/\lambda$

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$\Delta E_{light} + \Delta E_{atom} = 0$

Photon energy units are exchanged between light and atoms

$\Delta E_{light} + \Delta E_{atom} = 0$, that is $\Delta E_{light} = -\Delta E_{atom}$

Absorption of light:

Light loses (a photon of) energy, $\Delta E_{light} = -hc/\lambda$

Atom electron cloud gains energy, $\Delta E_{atom} = hc/\lambda$

$\Delta E_{light} + \Delta E_{atom} = 0$

Photon energy units are exchanged between light and atoms

$\Delta E_{light} + \Delta E_{atom} = 0$, that is $\Delta E_{light} = -\Delta E_{atom}$

Sketch the energy diagram of the atom corresponding to emission of blue light, $\lambda_{blue} = 420$ nm.

$\Delta E_{light} + \Delta E_{atom} = 0$

Photon energy units are exchanged between light and atoms

$\Delta E_{light} + \Delta E_{atom} = 0$, that is $\Delta E_{light} = -\Delta E_{atom}$

On the same energy axis, add the energy diagram corresponding to the atom then absorbing of red light, $\lambda_{red} = 710$ nm.

[Quiz] A student asked, "I understand the transfer of a photon of energy takes about 100,000 oscillations of the electric field. But won't the photon have moved away from the atom in that time." A good answer to this question is …

20% 1. The photon is attracted to the atom and so stays close by.

20% 2. The atom moves back and forth the with the photon.

20% 3. It is the tugs of the electric field that transfer the energy.

20% 4. The photon disappears after the first electric field oscillation, but its energy doesn't appear in the atom until all of the field oscillations are complete.

20% 5. Some other answer.

