Lecture 29 CH101 A1 (MWF 9 am) Fall 2016

[TP] Atom X that has an orange emission line (650 nm) with photon energy $E_{\text{orange}} = h\,c/(650\text{ nm})$ and a green emission line (510 nm) with photon energy $E_{\text{green}} = h\,c/(510\text{ nm})$. Which of the following statements are true about a single emission process of atom X?

20% 1. An atom of X can emit light with any amount of energy.
20% 2. An atom of X can emit light with energy between E_{orange} and E_{green}.
20% 3. An atom of X can emit light in multiples of E_{orange} or E_{green}.
20% 4. An atom of X can emit light only of E_{orange} or E_{green}.
20% 5. None of the above.

BOSTON UNIVERSITY 1

Lecture 29 CH101 A1 (MWF 9 am)

Wednesday, November 16, 2016

- Complete: Natural frequencies of atoms
- Light and matter exchange energy smoothly and slowly, http://goo.gl/Ac4HGM
- Light energy is exchanged in tiny amounts called photons
- Energy diagrams from light-matter resonance

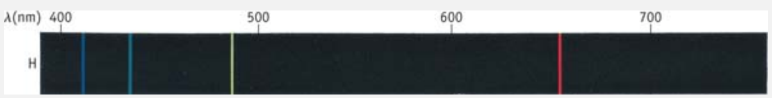
Next lecture: Electron waves and quantization

BOSTON UNIVERSITY

Lecture 29 CH101 A1 (MWF 9 am) Fall 2016

What are natural frequencies of atoms?

H atom emission spectrum



BOSTON UNIVERSITY 8

Lecture 29 CH101 A1 (MWF 9 am) Fall 2016

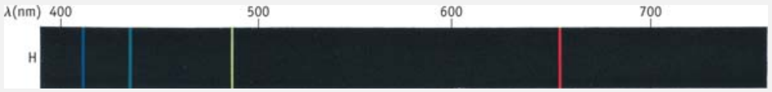
[TP] Atom X that has an orange emission line (650 nm) with photon energy $E_{\text{orange}} = h\,c/(650\text{ nm})$ and a green emission line (510 nm) with photon energy $E_{\text{green}} = h\,c/(510\text{ nm})$. Which of the following statements are true about a single emission process of atom X?

20% 1. An atom of X can emit light with any amount of energy.
20% 2. An atom of X can emit light with energy between E_{orange} and E_{green}.
20% 3. An atom of X can emit light in multiples of E_{orange} or E_{green}.
20% 4. An atom of X can emit light only of E_{orange} or E_{green}.
20% 5. None of the above.

BOSTON UNIVERSITY 9

What are natural frequencies of atoms?

H atom emission spectrum



The red light emitted has frequency 4×10^{14} Hz. IR light, due to the oscillation of protons and neutrons (nuclei), has a frequency of $\sim 1 \times 10^{13}$ Hz.

Estimate the ratio of the mass of the object oscillating in H atom that leads to the emission of visible light, relative to the mass of a proton.

BOSTON UNIVERSITY

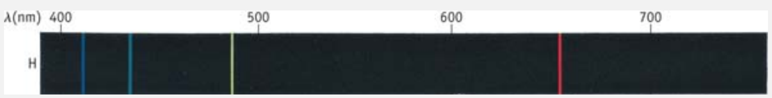
[TP] The red light emitted by H atoms has frequency 4×10^{14} Hz. The IR C-O stretch, due to the oscillation of protons and neutrons (nuclei), has a frequency of $\sim 1 \times 10^{13}$ Hz. This means that, compared to the moving mass in visible spectra, m_{atom}, the moving mass in IR spectra, m_{IR}, is

25% 1. ~ 15 times heavier
25% 2. ~ 150 times heavier
25% 3. ~ 1,500 times heavier
25% 4. ~ 15,000 times heavier

BOSTON UNIVERSITY

What are natural frequencies of atoms?

H atom emission spectrum



The red light emitted has frequency 4×10^{14} Hz. IR light, due to the oscillation of protons and neutrons (nuclei), has a frequency of $\sim 1 \times 10^{13}$ Hz.

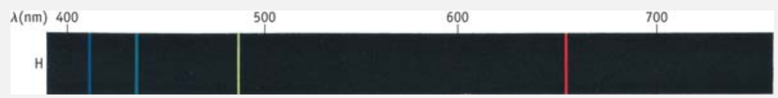
Estimate the ratio of the mass of the object oscillating in H atom that leads to the emission of visible light, relative to the mass of a proton.

$\nu_{atom}/\nu_{IR} \sim 40 = \sqrt{(m_{IR}/m_{atom})}$

BOSTON UNIVERSITY

What are natural frequencies of atoms?

H atom emission spectrum



The red light emitted has frequency 4×10^{14} Hz. IR light, due to the oscillation of protons and neutrons (nuclei), has a frequency of $\sim 1 \times 10^{13}$ Hz.

Estimate the ratio of the mass of the object oscillating in H atom that leads to the emission of visible light, relative to the mass of a proton.

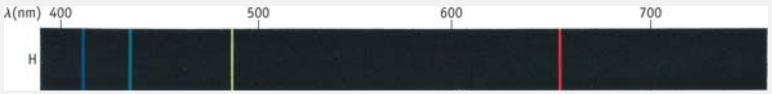
$m_{IR}/m_{atom} \sim 40^2$ so m_{IR} is ~ 1600 times heavier than m_{atom}

BOSTON UNIVERSITY

Lecture 29 CH101 A1 (MWF 9 am) Fall 2016 Copyright © 2016 Dan Dill dan@bu.edu

What are natural frequencies of atoms?

H atom emission spectrum



The red light emitted has frequency 4×10^{14} Hz. IR light, due to the oscillation of protons and neutrons (nuclei), has a frequency of $\sim 1 \times 10^{13}$ Hz.

Estimate the ratio of the mass of the object oscillating in H atom that leads to the emission of visible light, relative to the mass of a proton.

Motion is IR due to atoms, motion in atoms due to electron clouds.

14

Lecture 29 CH101 A1 (MWF 9 am) Fall 2016 Copyright © 2016 Dan Dill dan@bu.edu

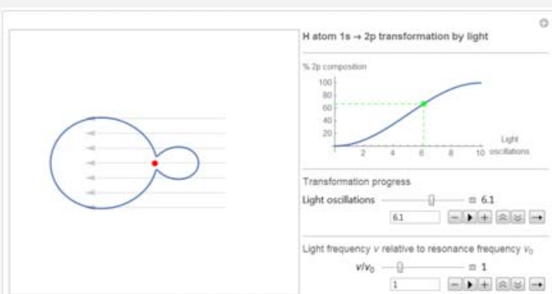
Light and matter exchange energy smoothly and slowly

15

Lecture 29 CH101 A1 (MWF 9 am) Fall 2016 Copyright © 2016 Dan Dill dan@bu.edu

Resonant tugs by light on an electron cloud

http://goo.gl/Ac4HGM



18

Lecture 29 CH101 A1 (MWF 9 am) Fall 2016 Copyright © 2016 Dan Dill dan@bu.edu

Non-resonant tugs by light on an electron cloud

http://goo.gl/Ac4HGM

19

Resonant tugs by light on an electron cloud

Each oscillation takes about $1/\nu \sim 10^{-14}$ seconds

About 100,000 oscillations are required to complete the transformation

So about 10^{-9} second are required to transform the 1s cloud into the 2p cloud.

BOSTON UNIVERSITY 32

Light energy is exchanged in tiny amounts called photons

BOSTON UNIVERSITY 33

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

This amount energy is called a photon.

BOSTON UNIVERSITY 34

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

Photon energy units are exchanged between light and atoms

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

Emission of light:

- Light gains (a photon of) energy, $\Delta E_{\text{light}} = h\,c\,/\,\lambda$
- Atom electron cloud loses energy, $\Delta E_{\text{atom}} = -h\,c\,/\,\lambda$

Absorption of light:

- Light loses (a photon of) energy, $\Delta E_{\text{light}} = -h\,c\,/\,\lambda$
- Atom electron cloud gains energy, $\Delta E_{\text{atom}} = h\,c\,/\,\lambda$

BOSTON UNIVERSITY 35

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

Photon energy units are exchanged between light and atoms

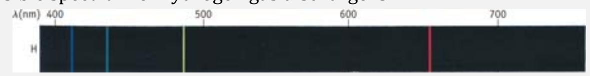
$$\Delta E_{light} + \Delta E_{atom} = 0$$

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

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

Energy diagrams from light-matter resonance

The visible spectrum of hydrogen gas discharge is

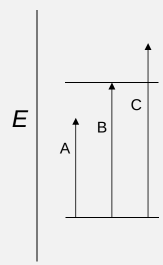


Why is their no emission at 600 nm?

Hint: Think about why IR absorption lines occur at particular wavenumbers?

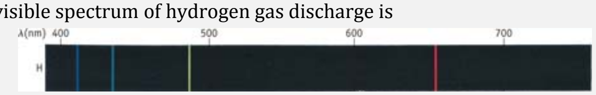
[Quiz] On the atom energy diagram, arrows represent possible photon energies. Which arrows correspond to light absorbed by the atom?

14% 1. Only A
14% 2. Only B
14% 3. Only C
14% 4. Only A and B
14% 5. Only B and C
14% 6. A, B, and C
14% 7. None of the above



Energy diagrams from light-matter resonance

The visible spectrum of hydrogen gas discharge is



Lines occur only when $\nu_{light} = \nu_{atom}$, i.e., when the frequency of oscillation of the electric field of the light matches a possible natural frequency (frequency of the "jiggling") of the atom electron cloud.

Since $\nu_{light} = E_{photon} / h$ and since $E_{photon} = |\Delta E_{atom}| = |E_f - E_i|$ ...

$$\nu_{atom} = |E_f - E_i| / h$$

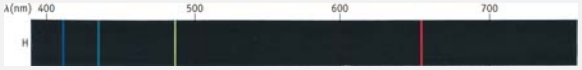
Therefore interaction happens only when ...

$$E_{photon} = |E_f - E_i|$$

Lecture 29 CH101 A1 (MWF 9 am) Fall 2016

Energy diagrams from light-matter resonance

The visible spectrum of hydrogen gas discharge is



Recipe to make the energy diagram that accounts for this spectrum.

1. Get lines values: 656.3 nm, 486.1 nm, 434.1 nm, and 410.2 nm.

2. Express energies in eV.

Lecture 29 CH101 A1 (MWF 9 am) Fall 2016 Copyright © 2016 Dan Dill dan@bu.edu

1 eV = energy of electron in a field of 1 V = 1 J/C

energy = charge × voltage

$e = 1.6021766 \times 10^{-19}$ C

eV = $e \times$ 1 J/C = $1.6021766 \times 10^{-19}$ J

$E_{\text{photon}} = h\, \nu_{\text{light}}$

$= h\, c\, /\, (656.3 \text{ nm})$

$= 3.027 \times 10^{-19} \text{ J} \times \dfrac{1 \text{ eV}}{1.6021766 \times 10^{-19} \text{ J}}$

$= 1.889$ eV

Lecture 29 CH101 A1 (MWF 9 am) Fall 2016 Copyright © 2016 Dan Dill dan@bu.edu

Energy diagrams from light-matter resonance

The visible spectrum of hydrogen gas discharge is

Recipe to make the energy diagram that accounts for this spectrum.

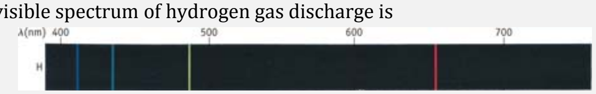
1. Get lines values: 656.3 nm, 486.1 nm, 434.1 nm, and 410.2 nm.

2. Express energies in eV: 1.889 eV, 2.551 eV, 2.856 eV, 3.023 eV

Lecture 29 CH101 A1 (MWF 9 am) Fall 2016 Copyright © 2016 Dan Dill dan@bu.edu

Energy diagrams from light-matter resonance

The visible spectrum of hydrogen gas discharge is



Recipe to make the energy diagram that accounts for this spectrum.

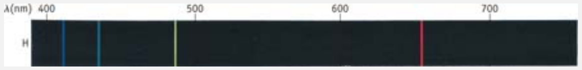
1. Lines at 656.3 nm, 486.1 nm, 434.1 nm, and 410.2 nm

2. Express energies in eV: 1.889 eV, 2.551 eV, 2.856 eV, 3.023 eV

3. Emission means energy given off by atom, so downward arrows.

Energy diagrams from light-matter resonance

The visible spectrum of hydrogen gas discharge is



Recipe to make the energy diagram that accounts for this spectrum.

1. Lines at 656.3 nm, 486.1 nm, 434.1 nm, and 410.2 nm

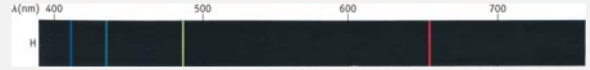
2. Express energies in eV: 1.889 eV, 2.551 eV, 2.856 eV, 3.023 eV

3. Emission means energy given off by atom, so downward arrows.

4. Assume all arrow end at the same place.

Energy diagrams from light-matter resonance

The visible spectrum of hydrogen gas discharge is



Recipe to make the energy diagram that accounts for this spectrum.

Carry out this recipe at home, making diagram to scale, in your notes.

