

Discharge Lamps

Introductory Question

- A fluorescent lamp tube is coated with a white powder on its inside surface. If that powder were not there, the lamp would appear
 - A. brighter
 - B. dimmer
 - C. about the same overall brightness, but with an unpleasantly bright white line near its center

Observations about Discharge Lamps

- They often take a few moments to turn on
- They come in a variety of colors, including white
- They are often whiter than incandescent bulbs
- They last longer than incandescent bulbs
- They sometimes hum loudly
- They flicker before they fail completely

4 Questions about Discharge Lamps

- Why phase out incandescent lamps?
- How can colored lights mix so we see white?
- How can white light be produced without heat?
- How do gas discharge lamps produce their light?

Question 1

- Why phase out incandescent lamps?

Shortcomings of Thermal Light

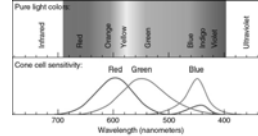
- Incandescent lamps are reddish and inefficient
- Filament temperature is too low, thus too red
 - The temperature of sunlight is 5800 K
 - The temperature of an incandescent lamp is 2700 K
- An incandescent lamp
 - emits mostly invisible infrared light,
 - so less than 10% of its thermal power is visible light.

Question 2

- How can colored lights mix so we see white?

Seeing in Color

- We have three groups of light-sensing cone cells
 - Their peak responses are to red, green, and blue light
 - Those are therefore the primary colors of light
- When the primaries mix, we see others colors
- When the primaries mix evenly, we see white

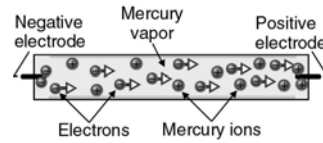


Question 3

- How can white light be produced without heat?

Fluorescent Lamps (Part 1)

- Fluorescent tubes
 - contain low density gas and metal electrodes,
 - which inject free electric charges into the gas
 - to form a plasma—a gas of charged particles
 - and electric fields cause current to flow in the plasma.



Clicker Question

- Both a gas and a plasma contain electric charges, so why can only a plasma conduct electric current?
- Each gas particle has zero net charge.
 - A gas has zero net charge.
 - A gas contains only negative charges.
 - Gas particles aren't mobile.

Clicker Question

- If electrons and atoms were both perfectly elastic balls, what would happen to the work done on the electrons by the lamp's electric field?
- It would become kinetic energy in the electrons.
 - It would become kinetic energy in the atoms.
 - It would be zero.
 - Collisions would turn it into thermal energy.

Fluorescent Lamps (Part 2)

- Collisions in the plasma cause
 - electronic excitation in the gas atoms
 - and occasionally ionize the gas atoms,
 - which helps to sustain the plasma.
- Excited atoms emit light through fluorescence
- Fluorescence is part of quantum physics

Quantum Physics of Atoms

- In an atom,
 - the negative electrons “orbit” the positive nucleus
 - and form standing waves known as orbitals.
 - Each orbital can have at most two electrons in it
- An electron in a specific orbital has a total energy,
 - that is the sum of its kinetic and potential energies.
- An atom’s electrons
 - are normally in lowest energy orbitals – the ground state
 - but can shift to higher energy orbitals – excited states.

Clicker Question

- The “levels” in a solid and the “orbitals” in an atom are both electron standing waves. Why are they different?
- A. Levels are much bigger than orbitals.
- B. Levels exist in a diffusely positive environment, while orbitals have a central positive nucleus.
- C. Levels have all the energy of a solid, while orbitals only have the energy of a single atom.

Atoms and Light

- Electron orbitals are standing waves:
 - they do not change with time
 - they involve no charge motion
 - they do not emit (or absorb) light.
- While an electron is changing orbitals,
 - there is charge motion and acceleration,
 - so the electron can emit (or absorb) light.
- Such orbital changes are called radiative transitions

Light from Atoms

- The wave/particle duality applies to light:
 - Light travels as a wave (diffuse rippling fields)
 - but is emitted or absorbed as a particle (a photon).
- An atom’s orbitals differ by specific energies
 - These energy differences set the photon energies,
 - so an atom has a specific spectrum of photons.

Photons, Energy, and Color

- Photon’s frequency is proportional to its energy
Photon energy = Planck constant · frequency
- and its frequency · wavelength = speed of light.
- Each photon emitted by an atom has
 - a specific energy,
 - a specific frequency,
 - a specific wavelength (in vacuum),
 - and a specific color when we see it with our eyes.

Atomic Fluorescence

- Excited atoms lose energy via radiative transitions
- During a transition, electrons shift to lower orbitals
- Photon energy is the difference in orbital energies
 - Small energy differences → infrared (IR) photons
 - Moderate energy differences → red photons
 - Big energy differences → blue photons
 - Even bigger energy differences → ultraviolet (UV) photons
- Each atom typically has a bright “resonance line”
- Mercury’s resonance line is at 254 nm, in the UV

Clicker Question

- A neon sign glows red because the neon
 - A. is red hot and its thermal radiation is red.
 - B. emits white light that goes through a red filter.
 - C. contains a red dye that glows red.
 - D. atom’s structure produces a red resonance line.

Clicker Questions

- Gas discharges involving a low-density gas of a single chemical element provide poor indoor illumination because
 - A. they are strongly colored.
 - B. they are too dim.
 - C. they get too hot.
 - D. they are dazzlingly bright.

Phosphors

- A mercury discharge emits mostly UV light
- A phosphor can convert UV light to visible
 - by absorbing a UV photon
 - and emitting a less-energetic visible photon.
 - The missing energy usually becomes thermal energy.
- Fluorescent lamps use white-emitting phosphors
 - They imitate thermal whites at 2700 K, 5800 K, etc.
- Specialty lamps use colored light-emitters
 - Blue, green, yellow, orange, red, violet, etc.

Introductory Question (revisited)

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Fluorescent Lamps (Part 3)

- Starting a discharge requires electrons in the gas
- Those electrons can be injected into the gas by
 - heated filaments with special coatings
 - or by high voltages
- Once discharge starts, it can sustain the plasma
- Starting the discharge damages the electrodes
 - Atoms are sputtered off the electrodes
 - Damage limits the number of times a lamp can start

Fluorescent Lamps (Part 4)

- Gas discharges are electrically unstable
 - Gas is initially insulating
 - Once discharge is started, gas become a conductor
 - The more current it carries, the better it conducts
 - Current tends to skyrocket out of control
- Stabilizing discharge requires ballast
 - Inductor ballast (old, 60 Hz, tend to hum)
 - Electronic ballast (new, high-frequency, silent)

Question 4

- How do gas discharge lamps produce their light?

Low-Pressure Discharge Lamps

- Mercury gas has its resonance line in the UV
 - Low-pressure mercury lamps emit mostly UV light
- Some gases have resonance lines in the visible
- Low-pressure sodium vapor discharge lamps
 - emit sodium's yellow-orange resonance light,
 - so they are highly energy efficient
 - but extremely monochromatic and hard on the eyes.

Clicker Question

- Greatly increasing the density and pressure of the gas in a discharge lamp will
 - A. make the discharge harder to start.
 - B. result in collisions during radiative transitions.
 - C. limit the emission of resonance photons.
 - D. All of the above.

Pressure Broadening

- High pressures broaden each spectral line
 - Collisions occur during photon emissions,
 - so frequency and wavelength become smeared out.
 - Collision energy shifts the photon energy

Radiation Trapping

- Radiation trapping occurs at high atom densities
 - Atoms emit resonance radiation very efficiently
 - Atoms also absorb resonance radiation efficiently
 - Resonance radiation photons are trapped in the gas
 - Energy must escape discharge via other transitions

High-Pressure Discharge Lamps

- At higher pressures, new spectral lines appear
- High-pressure sodium vapor discharge lamps
 - emit a richer spectrum of yellow-orange colors,
 - are still quite energy efficient,
 - but are less monochromatic and easier on the eyes.
- High-pressure mercury discharge lamps
 - emit a rich, bluish-white spectrum,
 - with good energy efficiency.
 - Adding metal-halides adds red to improve whiteness.

Summary about Discharge Lamps

- Thermal light sources are energy inefficient
- Discharge lamps produce more light, less heat
- They carefully assemble their visible spectra
- They use atomic fluorescence to create light
- Some include phosphors to alter colors