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?

A. Each gas particle has zero net charge.
B. A gas has zero net charge.
C. A gas contains only negative charges.
D. 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?

A. It would become kinetic energy in the electrons.
B. It would become kinetic energy in the atoms.
C. It would be zero.
D. 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 call 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)

- 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

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 becomes 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