Discharge Lamps

Turn off all electronic devices

Observations about Discharge Lamps

They often take moment 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

5 Questions about Discharge Lamps

1. Why phase out incandescent lightbulbs?
2. How can colored lights mix so we see white?
3. Why does a neon lamp produce red light?
4. How can white light be produced without heat?
5. How do gas discharge lamps produce light?

Question 1

Q: Why phase out incandescent lightbulbs?

A: Because they waste too much electric power.

Incandescent lightbulb is a thermal light source

- with a relatively low filament temperature of 2700 K
- It emits mostly invisible infrared light
- Less than 10% of its thermal power is visible light

Non-thermal light sources can be more efficient

Question 2

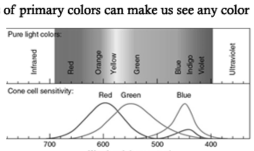
Q: How can colored lights mix so we see white?

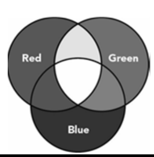
A: Primary colors of light trick our vision.

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

Mixtures of primary colors can make us see any color





Question 3

Q: Why does a neon lamp emit red light?

A: Neon's quantum structure dictates light emission

Electrons obey the rules of quantum physics

- In matter, electrons exist as quantum standing waves
  - three-dimensional patterns of nodes and antinodes
  - each wave "cycles" in place—it does not change with time
- In atoms, those standing waves are called orbitals
- In solids, those standing waves are called levels

Quantum structure dictates atom's light emission

Quantum Physics

Classical physics (pre-1900) thought that
- everything in nature is a particle or a wave
- electrons, atoms, and billiard balls are particles
- light and sound are waves

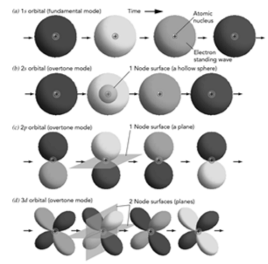
Modern physics (post-1900) recognizes that
- everything in nature is both particle and wave
- things are most wave-like when they are left alone
- things are most particle-like when they interact

Electrons in Matter

Electrons in matter
- exist as quantum standing waves
- have energies set by their waves

In atoms, waves are orbitals
- "orbit" an attractive charge
- oscillate in place (color change)

Orbitals differ in energy
- 1s orbital is lowest energy
- 2s orbital is second lowest
- 2p orbital is third lowest



Electrons in Matter (con't)

Electrons
- obey the Pauli exclusion principle:

  No two indistinguishable Fermi particles
  ever occupy the same quantum wave
- have two distinguishable states: spin-up or spin-down
- can occupy each wave alone or in pairs, but no more than that
- tend to occupy lowest energy waves, 2 electrons per wave

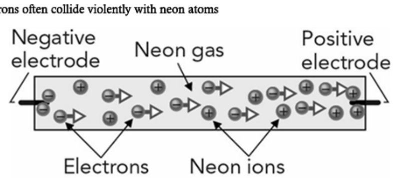
Electrons in a Neon Atom

Electrons in any atom
- tend to settle into the lowest energy orbitals
- cannot be more than 2 to an orbital
- Lowest energy arrangement is atom's ground state
- Higher energy arrangements are atom's excited states

In a neon atom,
- the nucleus has 10 protons
- electrical neutrality requires it to have 10 electrons
- ground state has electrons in 5 lowest-energy orbitals

Neon Discharge Lamps

Neon lamp
- metal electrodes inject free charges into dilute neon
- plasma forms—a vapor of charged particles
- electric field causes current to flow in the plasma
- current is mostly electrons streaming toward positive
- electrons often collide violently with neon atoms



Neon Lamps and Excited States

Collisions in the plasma
- occasionally ionize neon atoms, sustaining the plasma
- cause electronic excitations of the neon atoms

In a neon atom,
- electrons normally occupy ground state orbitals
- collisions can shift electrons to higher energy orbitals
- light emission can return them to lower energy orbitals

Atoms interact with light via radiative transitions

Radiative transition that emits light is fluorescence

Discharge Lamps 13

Light from Atoms

The quantum physics of light:
- Light travels as a wave (diffuse rippling fields)
- Light is emitted or absorbed as a particle (a photon).

A photon carries a specific amount of energy

Photon energy = Planck constant · frequency

An atom's orbitals differ by specific energies
- Orbital energy differences set the photon energies
- Excited atom emits a specific spectrum of photons

Discharge Lamps 14

Atomic Fluorescence

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 has its own fluorescence spectrum

Neon's fluorescence spectrum is dominated by red light

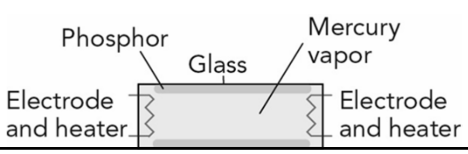
Discharge Lamps 15

Question 4

Q: How can white light be produced without heat?

A: Synthesize the proper mixture of primary colors.

Fluorescent tubes
- use a discharge in mercury gas to produce UV light
- UV light causes phosphors on the tube wall to glow
- phosphors synthesize white light from primary colors



Discharge Lamps 16

Phosphors

A mercury discharge emits mostly UV light

A phosphor can convert UV light to visible
- Absorb a UV photon, emit visible photon.
- Missing energy usually becomes thermal energy.

Fluorescent lamps use white phosphors
- They imitate thermal whites at 2700 K, 5800 K, etc.

Specialty lamps use colored phosphors
- Blue, green, yellow, orange, red, violet, etc.

Discharge Lamps 17

Starting Fluorescent Lamps

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

Discharge Lamps 18

Stabilizing Fluorescent Lamps

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 5

Q: How do gas discharge lamps produce light?

A: The discharge emits atomic fluorescence light, similar to neon

Some discharge lamps are based on low-pressure mercury vapor
- Mercury gas has its resonance line in the UV
- Low-pressure mercury lamps emit mostly UV light

Some low-pressure discharge lamps use visible resonance lines
- Low-pressure sodium lamps emit sodium's yellow-orange resonance light
- They are highly energy efficient, but extremely monochromatic
- Once popular on highways, they are now rarely used

High Pressure Effects

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 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