# 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

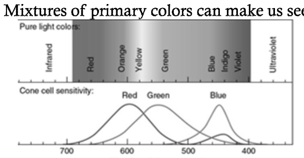
Q: How can colored lights mix so we see white?

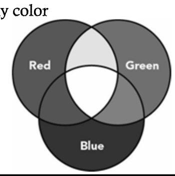
A: Primary colors of light trick our vision.

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 <u>quantum standing waves</u>
  - 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 <u>orbitals</u>
- In solids, those standing waves are called <u>levels</u>

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

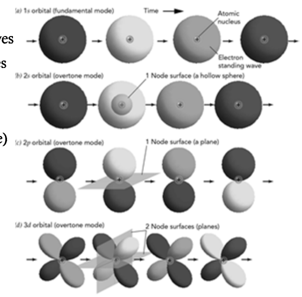


# Electrons in Matter

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

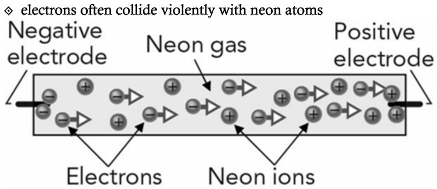
Electrons in any atom
- tend to settle into the lowest energy orbitals
- cannot be more than 2 to an orbital
- Lowest energy arrangement is atom's ground state
- Higher energy arrangements are atom's excited states

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

## 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



## 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



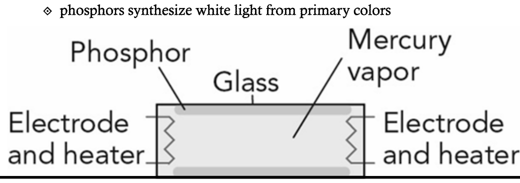
## Question 4

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






## 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.



## 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



## 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