Photon Energy and Sunscreen Molecule Absorption Worksheet

Objective

Calculate the energy of photons at different wavelengths and identify which sunscreen molecules are capable of absorbing or blocking them.

Photon Energy Formula

The energy of a single photon depends on its wavelength and is calculated using:

$$E = \frac{hc}{\lambda}$$

Where:

- E is energy in joules (J)
- $h = 6.626 \times 10^{-34}$ J $\cdot$ s (Planck's constant)
- $c = 3.00 \times 10^{8}$ m/s (speed of light)
- λ is the wavelength in meters (m)

To express energy in electronvolts (eV), we divide by the elementary charge:

$$E(\text{eV}) = \frac{hc}{\lambda} \cdot \frac{1}{e} \quad \text{where } e = 1.602 \times 10^{-19} \text{ C}$$

Substituting numerical values and converting nanometers to meters:

$$E(\text{eV}) = \frac{(6.626 \times 10^{-34})(3.00 \times 10^{8})}{(1.602 \times 10^{-19})(\lambda \times 10^{-9})}$$

$$E(\text{eV}) = \frac{1.986 \times 10^{-25}}{1.602 \times 10^{-28} \cdot \lambda} = \frac{1240}{\lambda \text{ (nm)}}$$

Therefore, the simplified formula:

$$E(\text{eV}) = \frac{1240}{\lambda \text{ (nm)}}$$

gives the energy of a photon in electronvolts when the wavelength is expressed in nanometers.

Clarifying the Constant e: Charge vs. Euler's Number

In the formula for photon energy in electronvolts:

$$E(\text{eV}) = \frac{hc}{\lambda} \cdot \frac{1}{e}$$

the symbol e refers to the **elementary charge**, not Euler's number.

- $e = 1.602 \times 10^{-19}$ C is the electric charge of a single electron or proton.
- It is used to convert energy from joules (J) to electronvolts (eV), since:

$$1 \text{ eV} = 1.602 \times 10^{-19} \text{ J}$$

In contrast, Euler's number $e \approx 2.718$ is a mathematical constant used in exponential functions, and is not involved in photon energy calculations.

Remember: In physics, always check whether a symbol like e refers to a physical constant or a mathematical one based on the context.

Types of UV Light

UV Band	**Wavelength Range (nm)**
UV-C	100–280
UV-B	280–315
UV-A	315–400

Sunscreen Molecule Absorption Ranges

Molecule	**Absorption Range (nm)**
Oxybenzone	270–350
Avobenzone	310–400
Octinoxate	280–320
Zinc oxide	280–400 (broad-spectrum)
Titanium dioxide	290–400 (broad-spectrum)

Exercise 1: Photon Energies

Use the formula $E(\text{eV}) = \frac{1240}{\lambda}$ to fill in the missing energies.

Wavelength (nm)	Energy (eV)
250	__________
280	__________
310	__________
350	__________
400	__________
500	__________

Exercise 2: Match Wavelengths to Absorbing Molecules

For each wavelength below, list all the sunscreen molecules from the table that are capable of absorbing or blocking that wavelength.

- 250 nm: ______________________________
- 280 nm: ______________________________
- 310 nm: ______________________________
- 350 nm: ______________________________
- 400 nm: ______________________________
- 500 nm: ______________________________

Why High-Energy Photons Are Dangerous to Skin

Light interacts with your body at the molecular level. When photons hit your skin, their effect depends on their **energy** — not just their brightness.

1. Breaking Bonds Requires Energy

Atoms in your skin (and DNA) are held together by **chemical bonds**. To break one of these bonds, a photon must have at least a certain amount of energy — usually around:

$$\text{Bond energy} \approx 3 \text{ eV to } 5 \text{ eV}$$

- UV-C photons (100–280 nm) have energies of **4.4–12.4 eV**
- UV-B photons (280–315 nm) have energies of **3.9–4.4 eV**
- These can **break molecular bonds**, causing mutations and damage.

2. DNA Damage

DNA molecules can be damaged if UV photons:

- Break bonds between nucleotides
- Cause incorrect chemical reactions (e.g., thymine dimers)

This can lead to:

- **Sunburn** (inflammation from damage)
- **Skin cancer** (from mutated cells)

3. Visible Light Is Not Dangerous in the Same Way

Even very bright red or green light has photon energies:

$$E2.5 \text{ eV}$$

That's not enough to break bonds — it might warm your skin, but it can't damage DNA.

4. Why Sunscreen Matters

Sunscreen blocks or absorbs UV photons **before** they can reach your skin's DNA. That's why it's critical to use:

- UV-B blockers (to prevent sunburn)
- UV-A blockers (to prevent long-term damage like aging and cancer)

Key Point

It's not about how much light hits you — it's about how powerful each photon is.

$$\text{If } E_{\text{photon}} > \text{Bond energy, damage can happen.}$$

$$\text{If } E_{\text{photon}} < \text{Bond energy, it can't cause harm — even if it's bright.}$$

Discussion Questions

1. Why can't red light (e.g., 600–700 nm) cause sunburn, even though it's bright?
2. Which molecules offer the best protection against UV-B? Against UV-A?
3. What does "broad-spectrum" mean in sunscreen labels?
4. Why is UV-C not usually a concern in daily sunscreen use?