This problem relates to a recent publication in *Science*, one of the premier journals in, well... science. (***Light-driven fine chemical production in yeast biohybrids***; *Science*, Vol. 362, Issue 6416, Nov 2018, pp. 813-816.) Here is the first part of the abstract from that paper:

> *Inorganic-biological hybrid systems have potential to be sustainable, efficient, and versatile chemical synthesis platforms by integrating the light-harvesting properties of semiconductors with the synthetic potential of biological cells. We have developed a modular bioinorganic hybrid platform that consists of highly efficient light-harvesting indium phosphide nanoparticles and genetically engineered Saccharomyces cerevisiae, a workhorse microorganism in biomanufacturing.*

1

The indium phosphide (InP) semiconductor was selected because it has a "bandgap" of 1.34 eV. Much to unpack here, but the important thing for us is that a 1.34 eV band gap means the InP nanoparticles can absorb 1.60×10^{-19} J photons and then use that energy to drive chemical processes carried out by the yeast cells.

- Determine the frequency and wavelength (in nm) corresponding to 1.60×10^{-19} J photons.
- Are the photons absorbed by the InP nanoparticles in the visible region, higher in energy, or lower in energy? Explain your reasoning.
- What is the energy of the photons kJ/mol?
- The energy required to break a molecular bond varies from around 200 kJ/mol to 1000 kJ/mol. Do these photons have enough energy to break molecular bonds?

2

A. Determine the frequency and wavelength (in nm) corresponding to 1.60×10^{-19} J photons. Write your final answers in the boxes provided below, and be sure to include the correct units.

$E = h\upsilon \Rightarrow \upsilon = E/h = (1.60 \times 10^{-19}\ J) / 6.626 \times 10^{-34} = 2.41 \times 10^{14}\ s^{-1}$

$c = \lambda\upsilon \Rightarrow \lambda = c/\upsilon = (2.998 \times 10^{8}\ m/s) / 2.41 \times 10^{14}\ s^{-1} = 1.24 \times 10^{-6}\ m$

$\times (10^{9}\ nm/m) = 1240\ nm$

3

Diffraction of electrons (caused by the constructive and destructive superposition of the matter waves, as we discussed in class) can be used to determine the arrangement of atoms on a solid surface if the wavelength of the electrons is comparable to the spacing between the atoms. So if the atoms are separated by 0.3 nm, you would need for the electrons to have a wavelength of about 0.3 nm.

What electron speed would be necessary to give you that wavelength?

$\lambda = h/(mv) \Rightarrow v = h/(m\lambda)$

$= 6.626 \times 10^{-34}\ J{\cdot}s / [9.109 \times 10^{-28}\ g \times (1\ kg/1000\ g) \times 0.3\ nm \times (1\ m/10^{9}\ nm)]$

$= 2424708.16...\ m/s\ (1\ sf) = 2._{4} \times 10^{6}\ m/s$

Note: Must convert g to kg.

4

The chain reactions in nuclear fission are caused by “fast” neutrons. The average speed for a neutron produced by nuclear fission is 20,000 km/s (Wikipedia). The mass of a neutron is given in the info pack. Calculate the wavelength of an average neutron produced by fission.

1.675×10^{-24} g => 1.675×10^{-27} kg

20,000 km/s => 2.0×10^{7} m/s

$\lambda = h/mv = 6.626 \times 10^{-34}$ J·s / (1.675×10^{-27} kg x 2.0×10^{7} m/s)

= 1.98×10^{-14}

The diameter of a neutron is around 2.2×10^{-15} m

5

Do you think wave equations are necessary to describe the behavior of a neutron traveling 20,000 km/s?

Yes

Explain.

The size of the wavelength (1.98×10^{-14} m) is comparable to (actually, it’s a bit longer than!) the size of the neutron (2.2×10^{-15} m), so the wave properties of neutron are important.

We can’t say where the neutron is in space with high precision. Instead, we are limited to knowing the probability it will be in a region of space.

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