Classroom Activity

10 Big Question: How can we reduce our reliance on fossil fuels?

Solar Spectrum Analysis

The solar spectrum is very important to the efficiency of a photocatalytic system. The use of TiO_2 as a semiconductor means that it is limited to only the high energy, UV, portion of the solar spectrum. However, it is possible to extend this to the visible part of the spectrum. By understanding the shape of the solar spectrum we can predict how much efficiency will be gained.

The graph below details the intensity of different frequency photons from the sun at the earth's surface. You will notice that this graph possesses a very distinct curve, with the highest intensity radiation occurring in the 'visible spectrum' (the component of the electromagnetic spectrum that we can see).Using the graph and the internet, investigate the following questions.

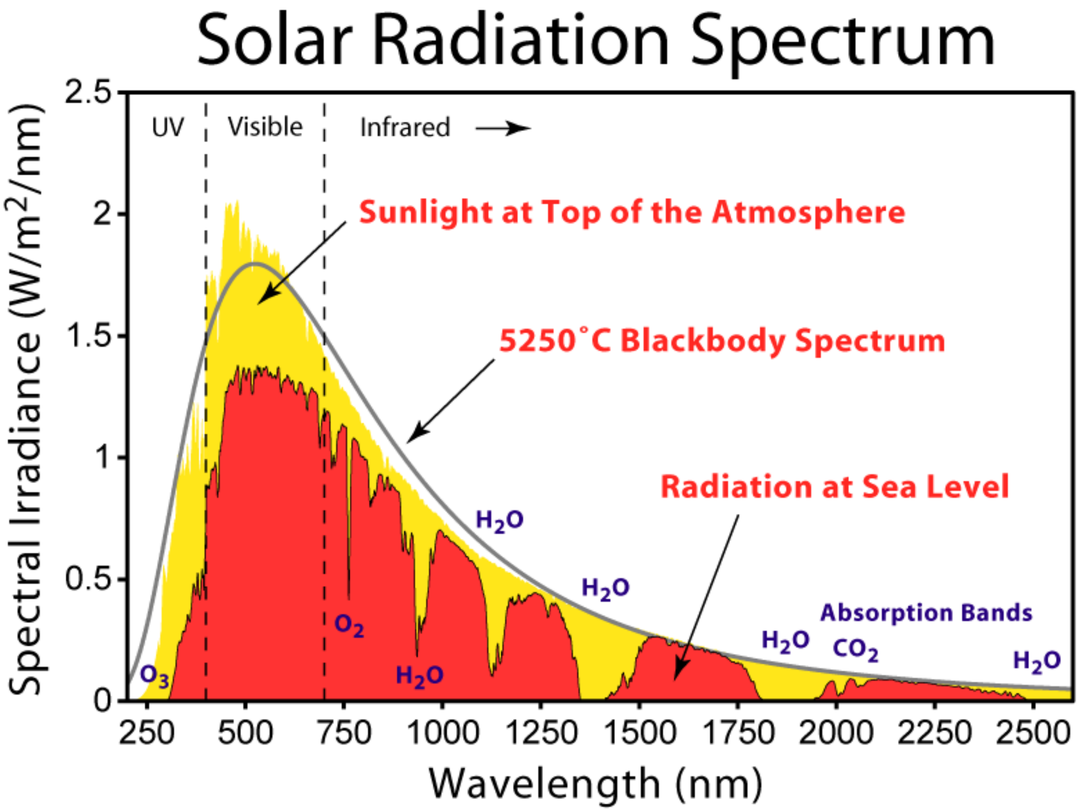

IMAGE: (CC BY-SA 3.0) Solar Spectrum by Global Warming Art

You can obtain a copy of this image here:
http://en.wikipedia.org/wiki/File:Solar_Spectrum.png

Questions

1. Explain why the solar spectrum graph that you obtained exhibits such a distinctive shape. Hint: look into something called a 'black-body radiator'.

2. TiO_2 possesses a band-gap of approximately 3.2 eV (387 nm), by considering the solar spectrum, explain why TiO_2's band-gap impedes its photocatalytic performance.

3. The intensity of the solar spectrum at the earth's surface shows a dip at a wavelength of approximately $3_{2}0$ nm, explain why this decrease in intensity exists at this specific wavelength.

See next page for answers

Answers

1. To understand the shape of the intensity curve in the solar spectrum we must consider the concept of a 'black-body radiator'. A black-body radiator is an object which absorbs all radiation incident on it (it is not reflective at all) and therefore appears perfectly black. In reality no such object can exist, but the idea of a black-body radiator is a useful concept for determining the temperature of a distant object such as a star. Any object with a temperature above absolute zero will emit a continuous spectrum of electromagnetic radiation with peak intensity at a wavelength that depends directly on the object's temperature. Beyond this peak, the radiation intensity will lessen and follow a curve that tends to zero in both directions (for an illustration of this, see the diagram linked to below). Because the peak intensity is temperature dependent it can be used to deduce the temperature of an object, as long as that object can be approximated as a 'black body'. The solar spectrum matches the black-body curve of an object with a surface temperature of approximately 5800 K. Here's a diagram that may help your understanding: http://quantumfreak.com/introduction-to-blackbody-radiation/

2. TiO_2 possesses a band gap of approximately 3.2 eV, thus it can only absorb photons with energy greater than 3.2 eV, because only these photons can excite valence band electrons across the band-gap to the conduction band. Therefore, the TiO_2 absorption spectrum corresponds to ultraviolet photons with a wavelength less than 387 nm. If you consider the solar spectrum, then it is clear that the intensity of these low wavelength (high energy) photons is very low compared to visible light; in fact they correspond to less than 5% of all incident solar radiation. Ultimately, the photocatalytic efficiency of TiO_2 is reduced because its band-gap allows it to absorb only a tiny proportion of the available solar energy.

3. The dip in intensity between 200 nm and 315 nm is caused by the ozone layer in the earth's atmosphere which absorbs ultraviolet radiation, and therefore prohibits this radiation from reaching the earth's surface. Below 200 nm, the low intensity arises due to O_2 and N_2 molecules in the atmosphere which absorb this radiation.