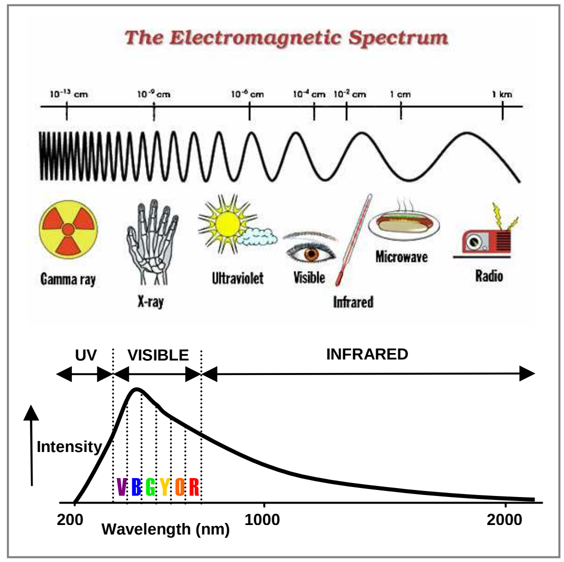
Energy Pathways in Earth's Atmosphere

Solar radiation reaching Earth's atmosphere includes a wide spectrum of wavelengths. In addition to *visible light* there is radiation of higher energy and shorter wavelength called *ultraviolet (UV)*, as well as radiation of lower energy and longer wavelength called *infrared*.

Some students may be familiar with black lights, which emit ultraviolet light, and heat lamps, which emit infrared light. Although these forms of light are invisible, they have a big effect on physical processes occurring in the atmosphere and at the surface of the Earth. Consequently, they are important factors in the health of the planet.



The graph at lower right shows the full spectrum of solar radiation. Nearly half of this energy is visible light, while most of the remainder is in the ultraviolet and infrared wavelengths.

Where does the incoming solar radiation (*irradiation*) go after it reaches the top of Earth's atmosphere?

- Approximately 22% of irradiation is reflected back into space as short-wave radiation by clouds, dust, and aerosols in the atmosphere.
- An additional 9% of irradiation is reflected back into space as short-wave radiation by Earth's surface.
- About 20% of irradiation is absorbed by the atmosphere.
- The remaining 49% of solar energy reaches Earth's surface and is absorbed by it.

In general terms, roughly half of solar radiation striking Earth is reflected or absorbed by the atmosphere, and half is absorbed by the surface – oceans, land areas, vegetation, etc.

Here is what happens to the 49% that is absorbed by the surface:

- All 49% of this energy is re-emitted as long-wave (infrared) radiation into the atmosphere, mainly through direct radiation but also through thermal air currents, evaporative heat loss, and other means.
- Greenhouse gases such as water vapor, carbon dioxide, and methane in the atmosphere capture long-wave radiation but also re-emit it back to the surface. In fact, there is a continuous back-and-forth exchange of long-wave radiation between the atmosphere and the surface.
- Eventually, all of the energy absorbed by the surface and atmosphere – 69% of total irradiation – is emitted back into space as long-wave radiation.

Notice how the numbers balance:

31%	reflected back into space as short-wave radiation
+ 69%	emitted back into space as long-wave radiation
100%	of irradiation

This balance says that the amount of solar energy entering Earth's atmosphere is exactly equal to the amount leaving the atmosphere. If this condition did not exist, the Earth would become increasingly warmer or cooler – to the point where it could not sustain life.

Complete this diagram to show what happens to 100 percent of solar radiation. Use arrows and labels to indicate the different energy pathways and percentages described on the previous page.

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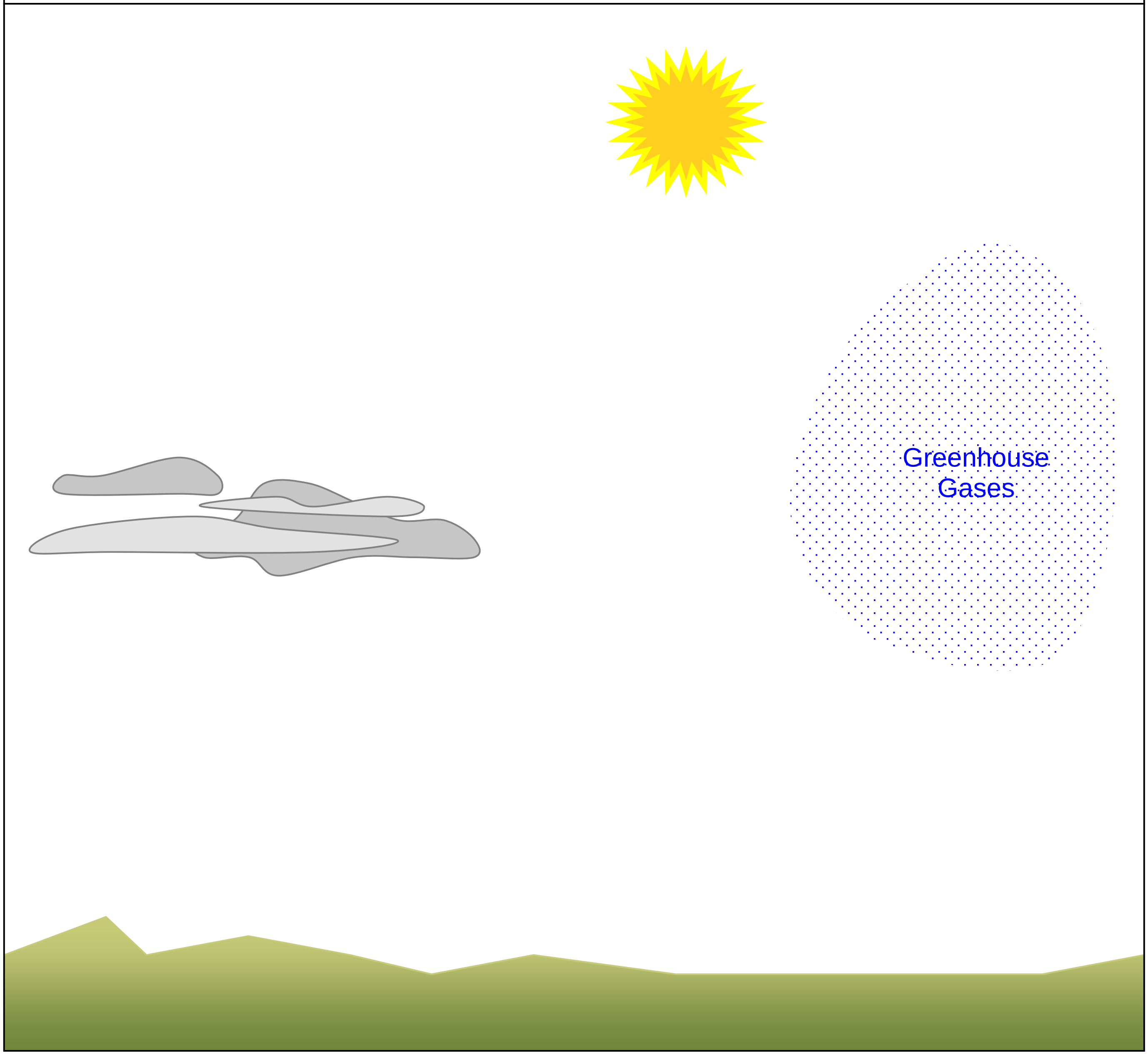
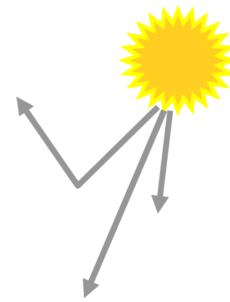


For all of Earth, the average incoming solar radiation is 342 watts per square meter (W/m^2). Use this fact and the given percentages to calculate quantities in W/m^2 for each of the following:

Total radiation reflected back to space:

Total radiation absorbed by surface:

Total infrared radiation re-emitted to space:



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Teachers' Notes

<u>Objectives</u>: Students will understand that solar radiation includes not only visible light but also energy of shorter and longer wavelengths, and that the energy reaching Earth follows different pathways through the atmosphere, to the surface, and back out into space. Students will describe these pathways in a diagram.

<u>Grade Level</u>: Middle/High

<u>NSES</u>: A3, A4, A5, A6, B6, B11, B12, D4, D6, D7

<u>NHSCF</u>: 4b, 5c, 5f, 5g, 6a, 6b, 6c

<u>Key Concepts</u>

Nearly half of all energy from the sun is in the *visible* part of the electromagnetic spectrum. Most of the remaining solar energy reaching Earth occurs as *ultraviolet* (a type of short-wave) and *infrared* (a type of long-wave) radiation, which are adjacent to the visible spectrum.

Solar energy is not evenly distributed on Earth; the intensity of solar radiation at any particular location depends on sun angle, which in turn depends on latitude and season. Incoming solar radiation is either reflected back into space or absorbed by the atmosphere or surface. Reflection or scattering of short-wave radiation occurs when it encounters water vapor, cloud droplets, ice particles, dust, or pollutants in the atmosphere.

The amount of reflected energy is a function of Earth's *albedo*, which is simply defined as the percentage of solar radiation reflected by a surface (often expressed as a decimal.) Earth's global albedo is approximately 0.31.

The amount of incoming solar energy absorbed by the atmosphere is roughly equal to the energy reflected by the atmosphere – around 20 percent. Nearly half of solar irradiation is absorbed by Earth's surface, including water bodies, land masses, and vegetation. Plants absorb solar energy directly in the process of *photosynthesis*, and return a significant portion of this energy to the atmosphere through *evapotranspiration*.

Absorbed short-wave radiation is converted to long-wave radiation (infrared) in the various media. This energy may be re-emitted from any warmer body to a cooler one (for example, warm soil into cool evening air), or it may be transmitted by *conduction* or *convection*. Conduction occurs at the molecule-to-molecule level as heat energy diffuses through a medium. Convection is the circulation of heat energy by thermal currents in air or water. In atmospheric physics, convection normally refers to strong vertical movements of air, while the term *advection* is used to denote strong horizontal air movements. Both derive from convective forces. Lastly, it should be mentioned that *latent heat* associated with the phase changes of water also plays a role in energy transfer within and between the atmosphere and surface.

Outgoing energy is a combination of reflected short-wave radiation (about 31% of incoming) and re-emitted long-wave (about 69% of incoming) radiation. Earth's energy budget requires that total solar irradiation be exactly equal to total energy radiated back into space. Otherwise, there would be a net gain or loss of energy for the planet, resulting in unchecked heating or cooling. While the recent global warming may signify a rise in the average temperature "set point" of the atmosphere (because of the greenhouse effect), the total outgoing radiation must remain in balance with the incoming solar radiation.

The energy flow diagram presented to students includes the major pathways by which solar radiation is absorbed and re-emitted in Earth's atmosphere. The diagram is a simplification of an illustration published by IPCC, available on its website at http://www.grida.no/climate/ipcc_tar/wg1/041.htm#121.

Questions for students to ponder:

- Why do you feel warmer when standing in direct sunlight than in shadow, even if the air temperature is the same? *Answer: In sunlight, some of the radiation is absorbed by your skin and clothing, causing them to heat up. A portion of this radiation is in the infrared part of the spectrum, the same type of radiation given off by heat lamps. Infrared radiation is instantly felt but not visible to the human eye. The warming effect of sunlight depends on its intensity (higher when overhead) and on the albedo, or reflectivity, of the receiving surface. The amount of solar energy absorbed by your body can be reduced by wearing lighter colors, or increased by wearing darker colors. In other words, if you want to be cool, raise your albedo!*

- What makes fluorescent paint appear so bright in daylight? *Answer: With ordinary paint, what you see is reflected visible light. With fluorescent paint, the light is both reflected and emitted. UV light from the sun excites fluorescent particles called phosphors in the paint, causing them to emit energy in the visible spectrum. The emitted light, added to the reflected light, is brighter than the reflected light alone.*

- What might Earth be like if it had a higher albedo, meaning more solar energy would be reflected back into space? *Answer: With more energy reflected, there would be less to be absorbed by the atmosphere and the surface. Consequently, Earth would be a colder planet than it is; and life as we know it would almost certainly not exist.*

For additional information, visit these websites:

http://www.grida.no/climate/ipcc_tar/wg1/041.htm#121.
http://eosweb.larc.nasa.gov/EDDOCS/radiation_facts.html
http://orpheus.nascom.nasa.gov/serts/learning_spectra.htm#spectrum
http://www.ucar.edu/learn/1_1_1.htm
http://www.weatherquestions.com/What_is_infrared_radiation.htm

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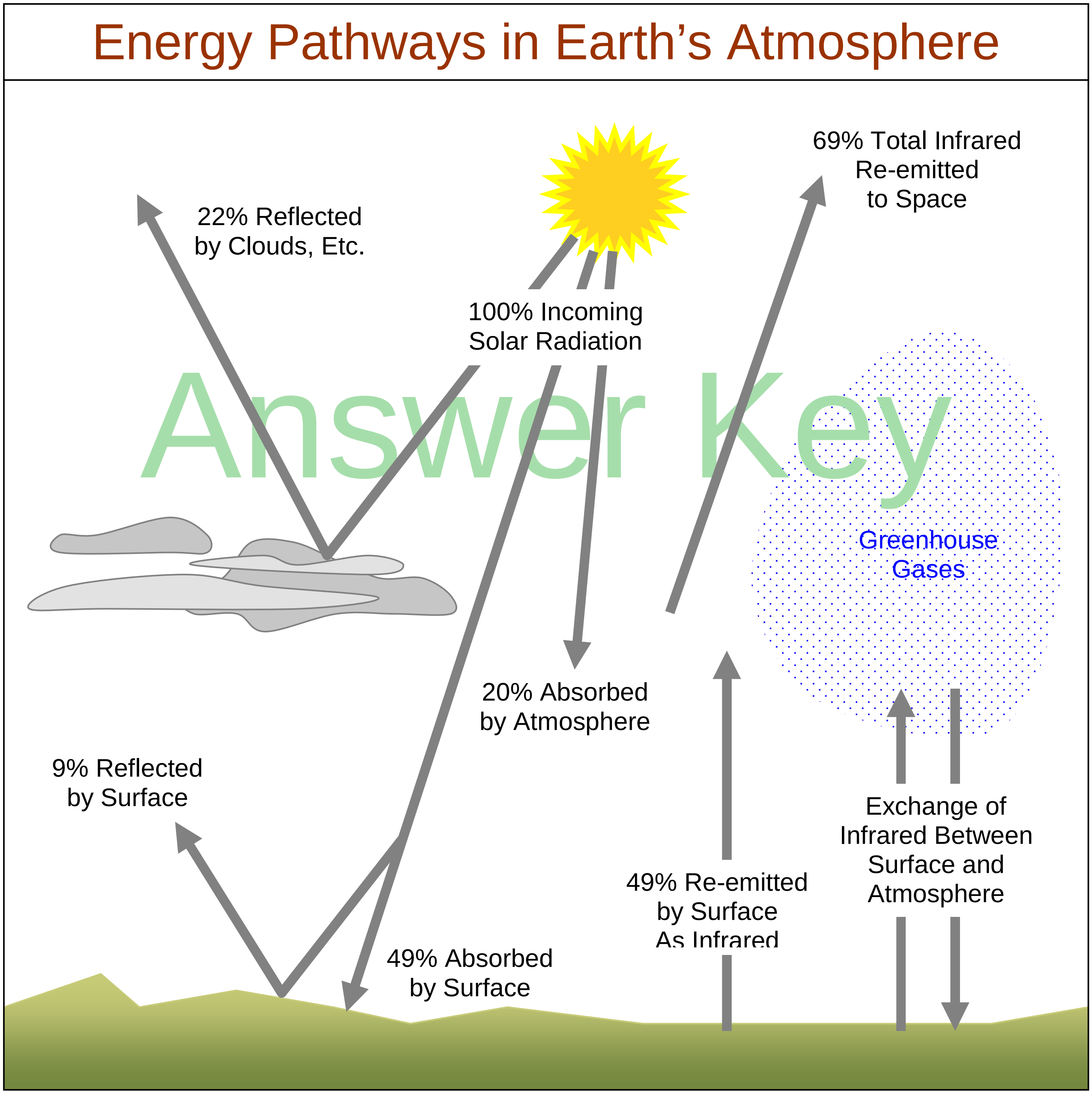

For all of Earth, the average incoming solar radiation is 342 watts per square meter (W/m^2). Use this fact and the given percentages to calculate quantities in W/m^2 for each of the following:

Total radiation reflected back to space: ***$342 \times (0.22 + 0.09) = 106\ W/m^2$***

Total radiation absorbed by surface: ***$342 \times (0.49) = 168\ W/m^2$***

Total infrared radiation re-emitted to space: ***$342 \times (0.69) = 236\ W/m^2$***