



ANSWER KEY

Student Worksheet 1

Students will have varying answers in their calculations depending on their exposed surface areas. The uncorrected irradiation should be around 450 J/s/m^2 in order to get the correct solar constant of 1370 J/s/m^2 .

Questions and Interpretations:

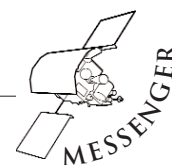
1. Students may come up with any number of reasons, including but not limited to: it may be a partly cloudy day, the correction numbers may not be exactly right for the experiment the students performed (depending on what type of collector they used), the thermometer may not be precise or easy to read, some of the heat is conducted to the environment, reflected from the bottle or the not-perfectly-black water (the amount of ink mixed in influences this), etc.

2. Solar constant \times surface area of sphere with radius $1\text{AU} = 1.5 \times 10^{11} \text{ m}$.

$$1370 \text{ J/s/m}^2 \times 4\pi(1.5 \times 10^{11})^2 \text{ m}^2 = 3.87 \times 10^{26} \text{ J/s (W)}$$

3. Solar constant \times cross-sectional area of Earth \times the number of seconds in one day

$$1370 \text{ J/s/m}^2 \times \pi(6.37 \times 10^6)^2 \text{ m}^2 \times 86400 \text{ s} = 1.51 \times 10^{22} \text{ J}$$





Student Worksheet 2

Planet	Mercury	Venus	Earth	Mars
Distance from the Sun (km)	58×10^6	108×10^6	150×10^6	228×10^6
Calculated average surface temperature (K)	448	328	278	226
Real average surface temperature (K)	440	737	288	210

1. Planets that have calculated temperatures close to (but not exactly the same as) the real average surface temperatures are Mercury, Earth, and Mars. Answers may vary as to why. Some possibilities include: we assume that there is nothing impeding the radiation on its way through the interplanetary medium, we assume that the planets absorb all of the heat that they receive, (while in reality some of it is reflected away), etc.

2. Venus is the only planet in the group that has a very different calculated surface temperature from the real surface temperature. The reason for this is that Venus's thick atmosphere lets through much of visible light but prevents the infrared radiation emitted by the hot surface from escaping. Venus's atmosphere consists mostly of carbon dioxide (CO_2), which is a significant greenhouse gas and largely responsible for creating this greenhouse effect.

3. If we solve our equation for the distance from the Sun, we get:

$$d = (R_s/2) (T_s/T)^2$$

$$d (T=273) = 156 \times 10^6 \text{ km}$$

$$d (T=373) = 84 \times 10^6 \text{ km}$$

We can now see that Earth is (barely) located within the Sun's habitable zone.

4. Some other sources of heat may include: internal heat from the planet, heat caused by tidal forces from another nearby object (e.g., tidal heating of Jovian moons by Jupiter), etc. Reasons that radiation may not be re-emitted include: absorption of radiation on planet by things like water, plants, etc., atmospheres inhibiting re-emission (i.e., the greenhouse effect), etc.





5. Since the energy received from the Sun is inversely proportional to the square of the distance from the Sun (as the equation for the surface area of the sphere shows), an object at Mercury's distance from the Sun will receive 11 ($1/0.3^2$) times as much energy as it would in space near Earth. (Mercury is 0.3 times the distance from the Sun to the Earth.) Some suggestions for protecting the spacecraft could include: shielding the spacecraft from the Sun, etc. See Science Overview for some of the solutions used in the mission. One might also want to try and stay on the dark side of Mercury, but that isn't feasible for an orbiting spacecraft intended to observe the planet's surface.

Student Challenge Worksheet

1. Intensity = power per unit area

Power radiated by the light bulb or the Sun is spread over an area $4\pi r^2$, where r is the distance to the light source (light bulb and Sun treated as point sources of light).

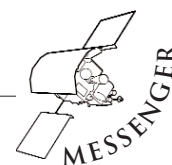
We now match intensity of lamp at distance D from the lamp with the intensity of the Sun at Earth's distance, r_E :

$$\begin{aligned} \text{Intensity}_{\text{Sun}} &= \text{Intensity}_{\text{light}} \\ \text{Power}_{\text{Sun}} / 4\pi r_E^2 &= \text{Power}_{\text{light}} / 4\pi r^2 \\ \rightarrow D^2 &= \text{Power}_{\text{light}} \times r_E^2 / \text{Power}_{\text{Sun}} \\ \rightarrow D &= (\text{Power}_{\text{light}} \times r_E^2 / \text{Power}_{\text{Sun}})^{1/2} \end{aligned}$$

For a 100-W light bulb, using the total power of the Sun, 3.83×10^{26} W, and Earth's distance from the Sun, 1.50×10^{11} m, this gives

$$D = 0.0766 \text{ m}$$

That is, radiation from a 100-W light bulb at the distance of 8 cm has the same intensity as sunlight arriving on Earth (on top of the atmosphere).





2. a) $1 \text{ W} = \text{J/s}$

$$\begin{aligned} 1 \text{ kWh} &= 1 \times 1000 \text{ W} \times 3600 \text{ s} \\ &= 3.6 \times 10^6 \text{ J/s} \times \text{s} = 3.6 \times 10^6 \text{ J} \end{aligned}$$

b) United States: 3600 billion kWh $= 3.60 \times 10^{12} \text{ kWh} = 1.30 \times 10^{19} \text{ J}$

World: 13900 billion kWh $= 1.39 \times 10^{13} \text{ kWh} = 5.00 \times 10^{19} \text{ J}$

c) Cross-sectional area of Earth facing the Sun at any given time:

$$\pi R_E^2 = 1.28 \times 10^{14} \text{ m}^2$$

where R_E is the radius of the Earth.

The amount of energy received by the Earth in one second:

$$E = 1370 \text{ J/s/m}^2 \times 1.28 \times 10^{14} \text{ m}^2 \times 1 \text{ s} = 1.75 \times 10^{17} \text{ J}$$

Length of time required to satisfy electricity consumption for one year:

$$t_{\text{USA}} = 1.30 \times 10^{19} \text{ J} / 1.75 \times 10^{17} \text{ J/s} = 74 \text{ s} = 1 \text{ min } 14 \text{ s}$$

$$t_{\text{world}} = 5.00 \times 10^{19} \text{ J} / 1.75 \times 10^{17} \text{ J/s} = 286 \text{ s} = 4 \text{ min } 46 \text{ s}$$

d) This is not possible, at least at present time. In order to do this, we would need to be able to build collectors capable of capturing 100% of the solar energy striking them, hoist them to a configuration above the atmosphere and have them operate reliably there. The technology to do this does not exist at the moment. It probably would not be popular to block out the Sun completely, and it would also have adverse effects on life forms—plants, animals, etc. If this could be done for a brief period of time every now and then, this objection might go away. But the main problem is that the technology to do this does not currently exist.

