Physics-131: Lab 1 **Prof. Anchordoqui**

Solar energy and the inverse square law

I. OBJECTIVES

- Understand the importance of the Sun for energy.
- Probe existing technology to design solar cars.
- Become familiar with the inverse square law.
- Link the use of energy from the Sun with space exploration.

II. BACKGROUND

The federal government has encouraged alternative forms of transportation due to a limited supply of oil and increasing environmental pollution. Solar cars, like the one exhibited in Fig. 1, are just one of many transportation concepts emerging. They demonstrate the energy transformations of solar (radiant) energy to electrical, and from electrical energy to mechanical (kinetic) energy.

Solar cars use solar cell panels instead of gasoline as the fuel. As a result, exhaust fumes and oil consumption are eliminated. The solar cell panel generates an electrical charge that is stored in a battery and used to provide energy as the vehicle is driven. The lighter the vehicle, the less energy used and the farther the vehicle will travel. In cloudy days, or at night, energy can be drawn from reserve batteries. In the near future, charge stations will be located on the road sides for quick battery charging. The amount of current produced by a photovoltaic cell is proportional to the amount of the light hitting the cell. Therefore, increasing light intensity or increasing the size of the cell itself will increase the power output of the cell. In order to construct a solar powered system that will work at maximum efficiency, numerous factors pertaining to the design must be considered.

The main goal of this lab is to address how the angle of the solar panel, in relation to the sunlight, could affect the performance of the car. Note that this is a very important task, because we can use the result in designing real solar cars. If the angle of the solar panel is important, cars must be designed so that the driver or an automated system can change the angle of the solar panel. If the angle is not important, then the solar panel may be mounted horizontally on the roof of the car. A secondary goal of this lab is to determine the solar panel efficiency and explore the performance of planetary rovers.

FIG. 1: Prototype solar car.

III. MATERIALS

- Miniature powered solar car; see Fig. 2.
- Stopwatch.
- Meter stick or tape measure.
- Balance scale.
- Protractor.

IV. ASSEMBLY AND OPERATION

A. Solar energy and solar panel orientation

From dawn to dusk, the sun travels from east to west across the sky. During the course of the day, a fixed solar cell will show an increase in power from sunrise to solar noon and a decrease from solar noon to sunset. There are several factors that cause this change in current output:

1. Over the course of the day, the Earth's rotation brings the solar panel closer to the sun from dawn to noon and further from the sun from noon to dusk. In Fig. 3, the path of light traveling during solar noon is shorter than the path at dawn.

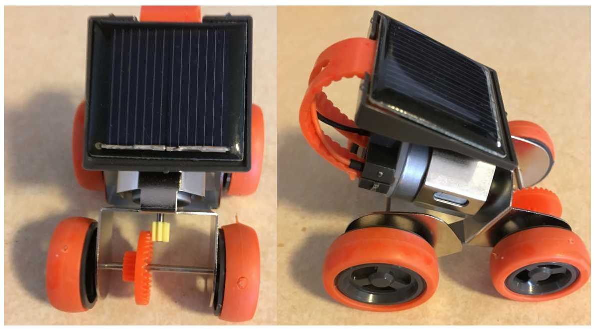


FIG. 2: Rookie Solar Racer v2, OWI-MSK681.

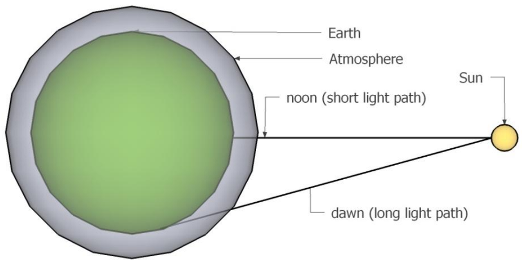


FIG. 3: Sunlight hitting the Earth at two times of the day.

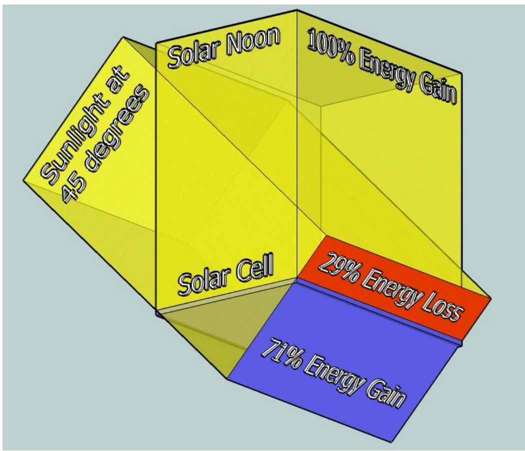


FIG. 4: Light hitting a solar panel directly (solar noon) and from an angle of 45°.

2. At dawn and dusk sunlight must travel through more of the Earth's atmosphere than at noon. Traveling through the atmosphere reduces the amount of sun that arrives at the solar cell. In Fig. 3, the light at solar noon travels through less atmosphere than the light at dawn.

3. Throughout the course of the day the Sun's angle changes in relation to the solar panel, causing changes in the solar panel's output. In Fig. 4, the solar panel is pointed directly up. Sunlight, represented by the yellow rectangle, shines down on the panel. At solar noon, the light shines directly down on the panel and 100% of the rectangle hits the face of the solar panel. When the sun is 45° off from normal to the panel face, 71% of the total rectangle hits the face of the solar panel and 29% misses the solar panel.

Although all these reasons are responsible for changes in current output, it is the third reason, the angle of the solar panel in relation to the Sun, which is improved by optimizing the angle.

In the first part of the lab you will study how the solar panel power is impacted by the angle of the Sun in relation to the face of the solar cell. On a sunny day, take your solar car outside on a smooth flat surface. Initially

TABLE I: Speed as a fucntion of the solar panel angle.

distance (m)	angle (degrees)	time (s)	speed (m/s)
1	0		
1	15		
1	20		
1	45		

adjust the solar panel to be horizontal. Place the car on the flat surface and record the distance it drives per second. That will be the speed. Move the solar panel to five different angles of your choice, and compare the resulting speed of the car. Measure the angles with a protractor and complete Table I. Make a bar graph with one vertical bar for each of the angles you test. The height of each bar will be the speed of your solar car in that angle. Report the sunlight exposure angle in which your solar car had the highest speed.

B. Solar panel efficiency

In the second part of the lab you will use conservation of energy to determine the solar panel efficiency on the (pesimistic) assumption that the car is moving on a frictionless surface. Use a balance scale to determine the mass of the car. Adjust the angle of the solar panel to provide maximum direct solar energy. Measure again the speed of the car and compute its total kinetic energy,

$$K = \frac{1}{2} m\, v^2\,, \qquad (1)$$

where m is the mass of the car and v its speed.This energy is provided by the sun hitting the solar panel. The solar energy density measured above the Earth atmosphere is 1,367 watts per meter square. Make a measurement of the size of the solar panel and using both the solar density and the time of data taken determine the percentage panel efficiency:

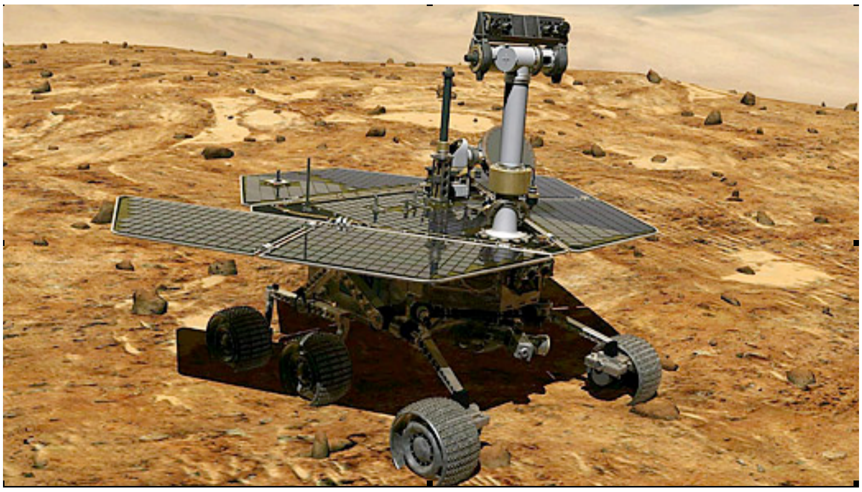
$$\text{efficiency} = \frac{K}{\text{solar energy}} \times 100\%\,, \qquad (2)$$

where

$$\text{solar energy} = \text{solar energy density} \times \text{area} \times \text{time}\,. \qquad (3)$$

C. Performance of the Martian rover Spirit

One of two rovers launched in 2003 to explore Mars and search for signs of past life, Spirit, far outlasted her planned 90-day mission. The Martian exploration rover (MER) Spirit is shown in Fig. 5. Among her myriad discoveries, Spirit found evidence that Mars was once much wetter than it is today and helped scientists better



Acronym: MER

Type: Lander/Rover

Status: Past

Launch Date: June 10, 2003
1:58 p.m. EDT (17:58 UTC)

Launch Location: Cape Canaveral Air Force Station, Florida

Landing Date: January 04, 2004
04:35 UTC

Mission End Date: May 25, 2011

Target: Mars

Destination: Gusev Crater, Mars

FIG. 5: Martian exploration rover Spirit. The solar panels have an area of 1.3 m^2.

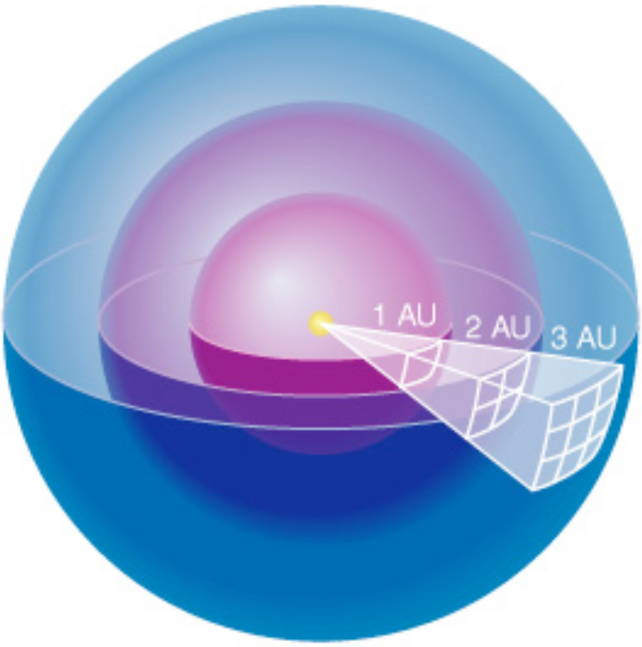


FIG. 6: The inverse square law.

understand the Martian wind. In May 2009, the rover became embedded in soft soil at a site called "Troy", with only five working wheels to aid in the rescue effort. After months of testing and carefully planned maneuvers, NASA ended efforts to free the rover and eventually ended the mission on May 25, 2011.

We know the Sun emits energy at a rate (i.e., has a total power output) of $L_\odot = 3.846 \times 10^{26}$ W. Consider a sphere centered on the Sun, and surrounding it at a radius of the Earth $r_{\text{Sun-Earth}} = 1$ A.U.. This situation is shown in the diagram of Fig. 6. If we assume the energy flows out isotropically (this means the flux is the same in all directions) from the source, then the energy received at any point on the sphere should be the same. It is easy to calculate the flux on the sphere, which is the total power output as it passes through the sphere (energy/ unit area/ unit time). It is just the total power output divided by the surface of the sphere. (Using the Sun-Earth distance = 1.496×10^{11} m convince yourself that you can reproduce the solar energy density.) Now, extend this idea to spheres at different radii: the surface area of each sphere increases as r^2, so the flux of the energy (per unit area) must reduce as $1/r^2$. This is known as the inverse square law.

Using the Sun-Mars distance = 1.524 A.U., make an estimate of the average solar flux density measured at Mars. Determine the speed of the solar car if it were to move in a similar (*frictionless*) region, but over the surface of Mars.

D. Solar racing

As a culminating activity, you will compete in a "Solar Sprint" race modeled after the National Renewable Energy Laboratorys Junior Solar Sprint competition. The winner will get 10 points of extra credits on the lab report. Get ready to race.