MATH AND SCIENCE @ WORK

AP* PHYSICS Educator Edition

LUNAR SURFACE INSTRUMENTATION: Part II

Instructional Objectives

Students will

- add, subtract and resolve displacement using unit-vector notation.
- evaluate two approaches, apply a set of constraints and choose the best alternative to the problem.

Degree of Difficulty

This problem is a straightforward application of vector concepts.

- For the average AP Physics student, the problem may be moderately difficult.

Background

This problem is part of a series of problems that apply math and science principles to human space exploration at NASA.

This problem builds from the *Math and Science @ Work Lunar Surface Instrumentation* problem. Students should complete the Lunar Surface Instrumentation problem first, in order to better understand the importance of extrahabitat activities (EHA) during long-duration human missions to the surface of the Moon and other planetary bodies.

AP Course Topics

Newtonian Mechanics

- Kinematics (including vectors, vector algebra, components of vectors, coordinate systems, displacement, velocity, and acceleration)
  - Motion in one dimension.

NSES Science Standards

Science and Technology

- Abilities of Technological Design.

History and Nature of Science

- Science as a Human Endeavour.

Grade Level
11-12

Key Topic
Vector Addition

Degree of Difficulty
Physics B,C: Moderate

Teacher Prep Time
5 minutes

Problem Duration
30 minutes

Technology
Calculator

Materials
Student Edition including:
- Problem worksheet

NSES
Science Standards
- Science and Technology
- History and Nature of Science

Problem Situation

NASA hopes to soon execute long-duration missions to the surface of the Moon and other planetary bodies. You are a member of the mission planning team at NASA Johnson Space Center. Your team needs to develop a plan for three instruments located around a polar region lunar outpost that need to be serviced by an astronaut resident at that lunar outpost. This servicing will be accomplished by an astronaut putting on a space suit to walk around the lunar surface in an extrahabitat activity or EHA.

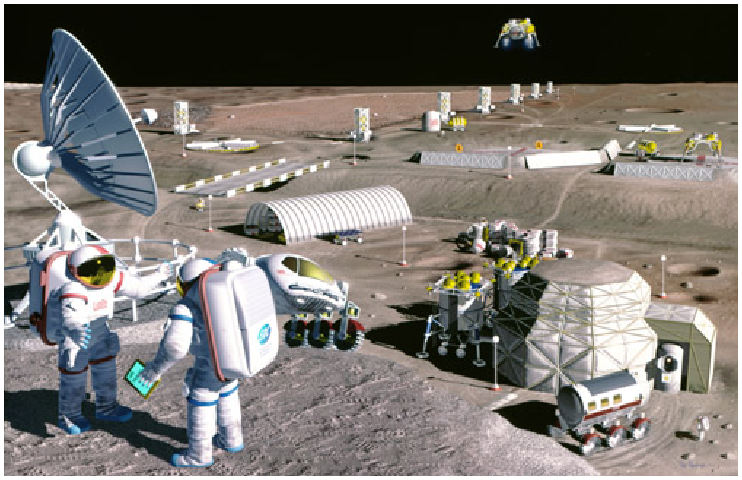

Figure 1: Astronauts on an EHA near a Lunar outpost (NASA concept)

Assuming a Cartesian coordinate system where the positive *x*-axis is east and the positive *y*-axis is north, relative to the habitat airlock at the origin, the three instruments are located:

1. 200 m, southwest,
2. 175 m, 15º north of west, and
3. 150 m, 30º west of north.

Constraints

The constraints applicable to developing the plan are as follows:

1. An astronaut can carry a maximum of 25 kg when walking.
2. An astronaut can use a lunar surface transporter (a remote controlled, battery-powered “cart” with wheels) with a maximum load of 100 kg on it. The astronaut will walk alongside the transporter and therefore, cannot carry anything while controlling the transporter.
3. An astronaut can walk 6 kilometers per hour (km/h) when unburdened, 4 km/h when carrying a load, and 3 km/p when controlling a lunar surface transporter (loaded or unloaded).
4. During such an activity, astronauts will carry their own life support system and supplies (e.g. water and breathable air) with total capacity for 5 hours.
5. When an astronaut returns to the habitat, they must have a minimum reserve life support supplies for 1 hour remaining in their life support system.
6. The equipment to be installed at the three instruments is the following:

a. One 20 kg sample cell at Instrument #1,

b. Two 15 kg lens component at Instrument #2, and

c. One 25 kg camera at Instrument #3.

7. The installation times involved at the three instruments are as follows:

a. 20 minutes to install the sample cell at Instrument #1,

b. 15 minutes to install each lens component at Instrument #2, and

c. 45 minutes to install the camera at Instrument #3.

Mission Planning

As a member of that mission planning team, your assignment is to examine two approaches for the astronaut's EHA. The primary selection criterion is the amount of life support supplies available at the end of the activities and whether that amount meets the constraint. The two EHA approaches are:

1. Use a lunar surface transporter to carry all the equipment for the three instruments; or

2. Carry one set of equipment at a time to each of the three instruments from the habitat airlock.

Problem

A. Sketch the instrument locations with the origin at the airlock.

B. Using the sketch from Question A and the provided information:

I. Determine the instruments' locations (x, y) from the airlock. Round your answers to the nearest tenth of a meter.

II. Determine the astronaut's displacement (using unit-vector notation) from the airlock when she is standing at each instrument. Round your answer to the nearest tenth of a meter.

C. Subject to the constraints, determine the total distance the astronaut would walk for each of the two EHA approaches to service the instruments. Round your answer to the nearest tenth of a meter.

I. Utilizing a lunar surface transporter to carry all equipment.

II. Carrying loads to each instrument.

D. Subject to the constraints, determine the time it would take for the astronaut to travel and service the instruments for each of the two EHA approaches. Round your answer to the nearest tenth of a minute.

I. Utilizing a lunar surface transporter to carry all equipment.

II. Carrying loads to each instrument without use of lunar surface transporter.

E. Explain which approach is more efficient in terms of:

   I. The distance the astronaut walks.

   II. The amount of reserve time remaining in the astronaut's life support system when she arrives back at the airlock.

Solution Key (One Approach)

Encourage students to check their answers throughout the solution for reasonableness of their answers. They can check the reasonableness of their solutions against the diagram they sketch to answer question A.

A. Sketch the instrument locations with the origin at the airlock.

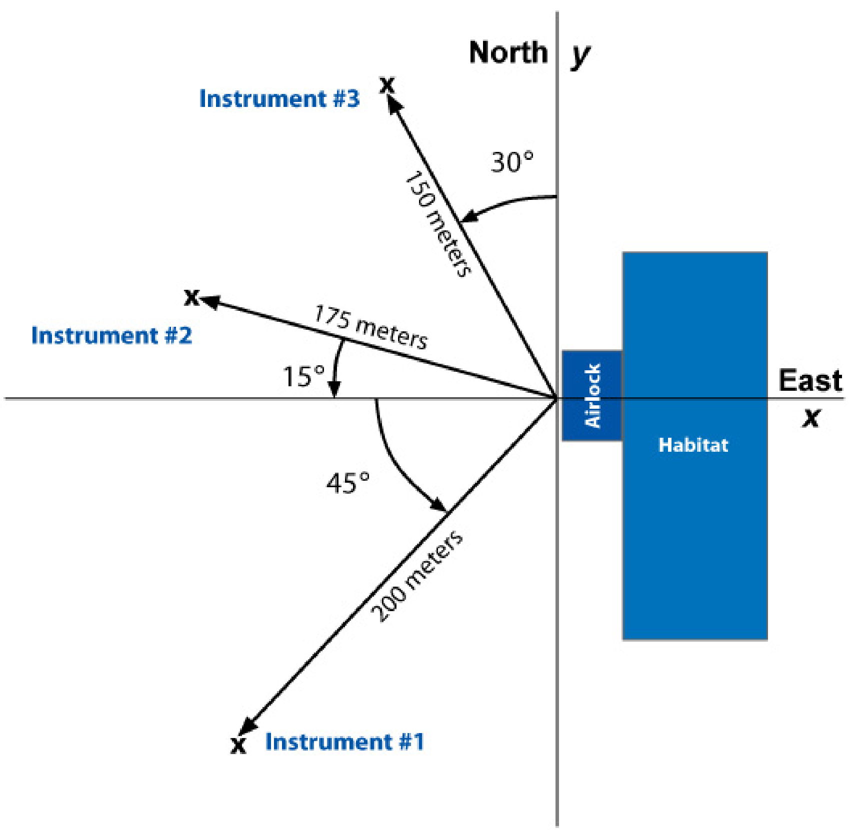

Figure 2: Locations of the lunar surface instruments

B. Using the sketch from Question A and the provided information:

   I. Determine the instruments' locations (x, y) from the airlock. Round your answers to the nearest tenth of a meter.

   Students should find the (x, y) components of each vector of the trip in order to find the position of the instruments.

Instrument #1: $x = 200\cos(225°) = -141.4$ m
$y = 200\sin(225°) = -141.4$ m

Instrument #2: $x = 175\cos(165°) = -169.0$ m
$y = 175\sin(165°) = 45.3$ m

Instrument #3: $x = 150\cos(120°) = -75.0$ m
$y = 150\sin(120°) = 129.9$ m

II. Determine the astronaut's displacement (using unit-vector notation) from the airlock when she is standing at each instrument. Round your answer to the nearest tenth of a meter.

Instrument #1: $(-141.4i, -141.4j)$ m

Instrument #2: $(-169.0i, 45.3j)$ m

Instrument #3: $(-75.0i, 129.9j)$ m

C. Subject to the constraints, determine the total distance the astronaut would walk for each of the two EHA approaches to service the instruments. Round your answer to the nearest tenth of a meter.

I. Utilizing a lunar surface transporter to carry all equipment.

Step 1: Determine the total mass of all the equipment (75 kg), is within the constraints for utilizing a lunar surface transporter (<100 kg).

Step 2: Sketch the path taken by the astronaut. Place the coordinate system origin at the airlock door.

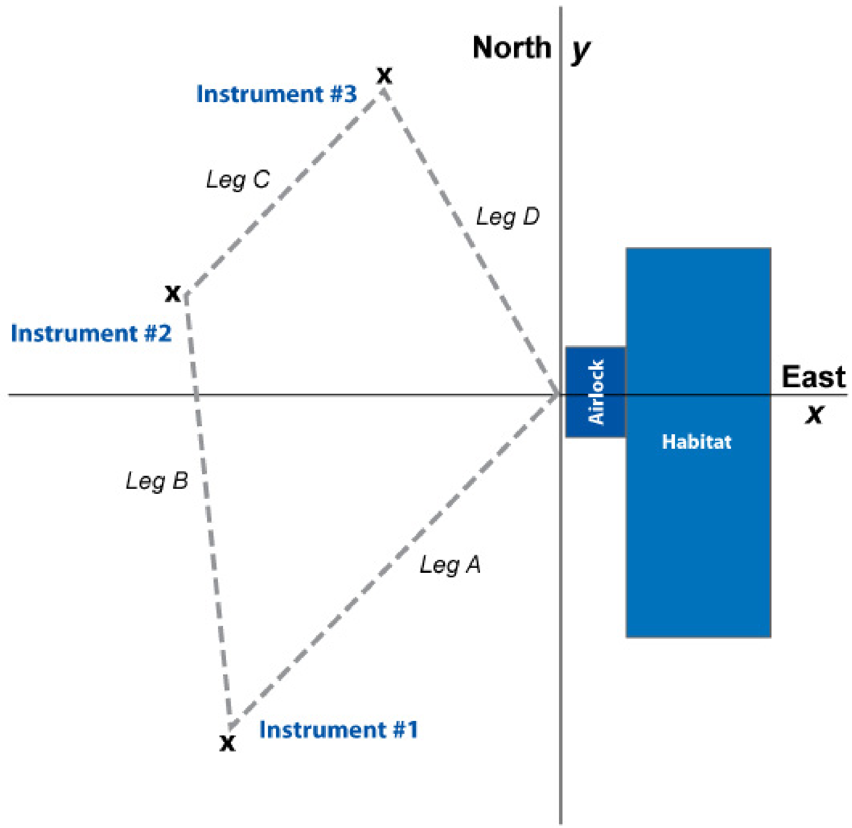

Figure 3: Astronaut path taken when using the lunar surface transporter

Step 3: Determine the length of each segment.

Leg A: $d_A = 200\text{ m}$ (given)

$$d_B = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}\text{ m}$$

Leg B: $$d_B = \sqrt{(-169.0 - (-141.4))^2 + (45.3 - (-141.4))^2}\text{ m}$$
$$d_B = 188.7\text{ m}$$

Leg C: $$d_C = \sqrt{(-75.0 - (-169.0))^2 + (129.9 - 45.3)^2}\text{ m}$$
$$d_C = 126.5\text{ m}$$

Leg D: $d_D = 150\text{ m}$ (given)

Step 4: The total distance is the summation of the four legs.

$$d_{TOT} = d_A + d_B + d_C + d_D$$
$$d_{TOT} = 200 + 188.7 + 126.5 + 150$$
$$d_{TOT} = 665.2\text{ m}$$

II. Carrying loads to each instrument.

Step 1: Determine that the constraints will require two trips to carry the 30 kg total mass to instrument #2, while the other instruments will require only one trip.

Step 2: Overall distance the astronaut travels while carrying mass from the airlock to the instruments is.

$$d_{TO} = 200 + (2 \cdot 175) + 150$$
$$d_{TO} = 700 \text{ m}$$

Step 3: Overall distance that astronaut travels without carrying a load from the instruments to the airlock is.

$$d_{FROM} = 200 + (2 \cdot 175) + 150$$
$$d_{FROM} = 700 \text{ m}$$

Total distance traveled is 1400 m.

D. Subject to the constraints, determine the time it would take for the astronaut to travel and service the instruments for each of the two EHA approaches. Round your answer to the nearest tenth of a minute.

I. Utilizing a lunar surface transporter to carry all equipment.

Step 1: Determine the total time taken to walk from the airlock to each instrument and back to the airlock.

$$t = \frac{d_{TOT}}{\text{rate}}$$
$$t = \frac{665.2 \text{ m}}{3 \text{ km/h}}$$

Note: convert to m/s

$$t = \frac{665.2 \text{ m}}{0.833 \text{ m/s}}$$

$$t = 798.56 \text{ s}$$

$$t = 13.3 \text{ minutes}$$

Step 2: Determine the service time for each instrument.

Instrument #1: 20 minutes (given)

Instrument #2: 15 minutes for each of two, 30 minutes total

Instrument #3: 45 minutes (given)

Step 3: Total time to accomplish the EHA by using the lunar surface transporter.

$$t_{TOT} = 13.3 + 20 + 30 + 45$$
$$t_{TOT} = 108.3 \text{ minutes}$$
$$t_{TOT} = 1 \text{ hour } 48.3 \text{ minutes}$$

II. Carrying loads to each instrument without use of lunar surface transporter.

The speed of walking to the instrument carrying the equipment is 4 km per hour, and the unburdened return trip speed is 6 km per hour.

Step 1: Determine the total time taken to walk to and from the instruments.

$$t = \left(\frac{d_{TO}}{4\text{ km/h}}\right) + \left(\frac{d_{FROM}}{6\text{ km/h}}\right)$$

Note: convert to m/s

$$t = \left(\frac{700\text{ m}}{1.11\text{ m/s}}\right) + \left(\frac{700\text{ m}}{1.67\text{ m/s}}\right)$$

$$t = 1049.79\text{ seconds}$$

$$t = 17.5\text{ minutes}$$

Step 2: Determine the service time for each instrument:

Instrument #1: 20 minutes (given)

Instrument #2: 15 minutes for each of two, 30 minutes total

Instrument #3: 45 minutes (given).

Step 3: Determine the total time to accomplish the EHA by walking to each instrument:

$$t_{TOT} = 17.5 + 20 + 30 + 45$$

$$t_{TOT} = 112.5\text{ minutes}$$

$$t_{TOT} = 1\text{ hour } 52.5\text{ minutes}$$

E. Explain which approach is more efficient in terms of:

I. The distance the astronaut walks.

Using the lunar surface transporter, the astronaut would walk 734.8 m less than if she carried the loads to each instrument without it.

II. The amount of reserve time remaining in the astronaut's life support system when she arrives back at the airlock.

The first approach, using the lunar surface transporter, is 4.2 minutes faster than the second approach and would leave more reserve time remaining in the astronaut's life support system.

Scoring Guide

Suggested 15 points total to be given.

Question		Distribution of points
A	*2 points*	1 point for a sketch in the correct orientation 1 point for correct angle measurements shown on sketch
B	*3 points*	1 point for correctly using cosine function to find the *x*-coordinates of the instruments 1 point for correctly using the sine function to find the *y*-coordinates of the instruments 1 point for correct conversion to vector notation for the three instrument locations
C	*5 points*	1 point for recognizing that the constraints for mass will be met using the lunar surface transporter 1 point for correct use of distance formula or Pythagorean theorem to find the distance from instrument #1 to #2 and from #2 to #3 1 point for finding the correct total distance using the lunar surface transporter 1 point for recognizing that the constraints will require two trips to instrument #2 when carrying the loads without use of lunar surface transporter 1 point for finding total distance traveled when not using lunar surface transporter
D	*3 points*	1 point for correctly finding total time to travel from airlock to each instrument and back to the airlock when using lunar surface transporter 1 point for correctly finding the time to service each instrument 1 point for correctly finding the total time to travel to and from the instruments when not using the lunar surface transporter
E	*2 points*	1 point for correctly identifying use of the lunar surface transporter as the more efficient approach in terms of distance the astronaut walks 1 point for correctly identifying use of the lunar surface transporter as the more efficient approach in terms of the amount of reserve time remaining in life support system

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