Net Force and the Acceleration of Spacecraft

Introduction

Here's the thing about space—it's big. Really really big. Which means it is really really difficult to explore. Say we send a spacecraft to the nearest star that isn't the sun. Traveling at the speed of light it would take the spacecraft 4.25 years to get there. Maybe that doesn't seem too bad to you, but it'd mean sending something into space almost 2000 times further than any man-made spacecraft has ever traveled, and doing so at the speed of light, something no spacecraft has come close to doing…yet.

The motion of all objects, including spaceships, is dictated by Newton's laws. Position, velocity, and acceleration are all that's needed to describe *how* objects move, but Newton's laws are necessary to explain *why* the motion takes place and why it changes.

For example, in the absence of **net force** (a push or pull that isn't balanced or counteracted), an object continues its motion without change—it keeps moving at the same speed and in the same direction. This is the essence of Newton's first law, represented by **Figure 1a**. When a net force acts on an object, as shown in **Figure 1b**, its velocity changes—it speeds up, slows down, or changes direction.

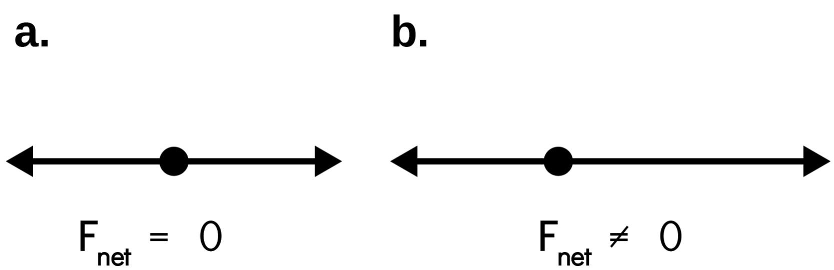


Figure 1. Balanced and Unbalanced Forces. A free body force diagram of **a)** an object acted on by two balanced forces, has no net force on it; and **b)** An object acted on by two unbalanced forces experiences a net force.

The rate at which the object's velocity changes when acted on by a net force is its acceleration. Acceleration is proportional to the net force and inversely proportional to the object's mass. That is, the larger the net force, the faster the object will accelerate; and the more massive the object, the slower it will accelerate. These relationships are captured by the equation below:

$$\mathbf{F_{net} = ma}$$

This is Newton's second law. In this lesson, we will use Newton's second law to explore how researchers are trying to reach for the stars—literally.

What To Do

Answer the analysis questions below, reading the Bite when instructed.

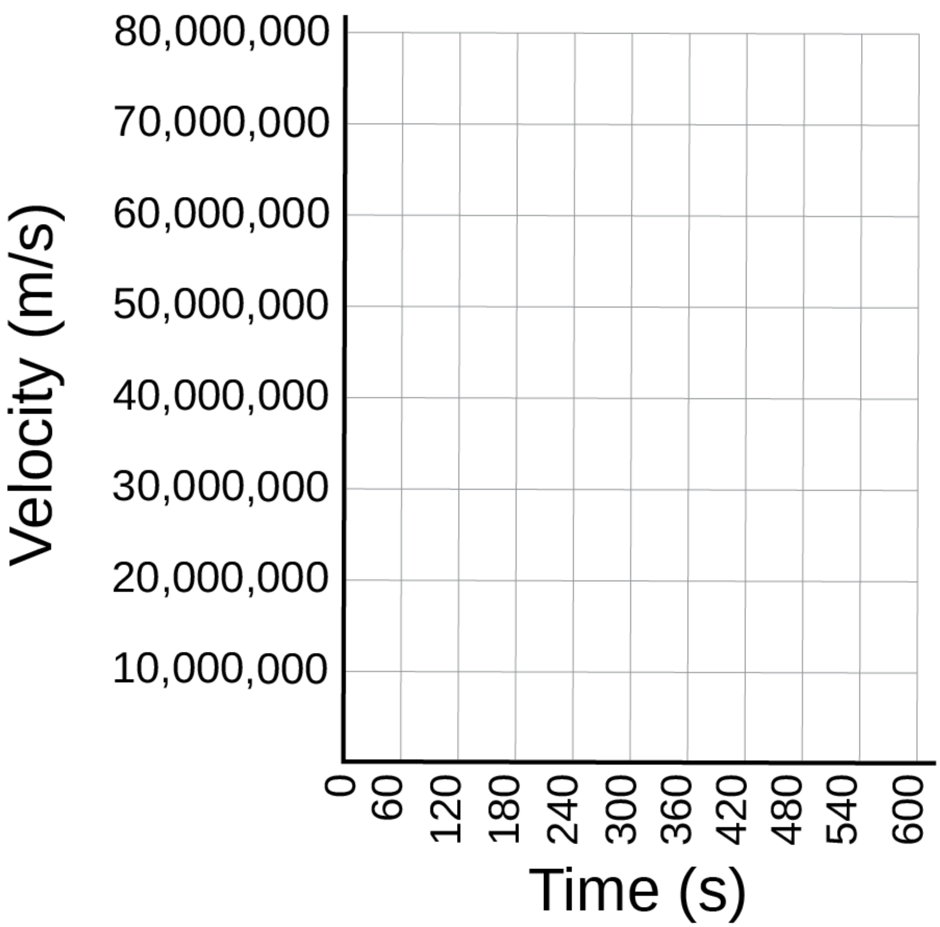
Analysis Questions

1. To study far away objects, researchers are considering ways to quickly accelerate a very tiny spacecraft. Why is it advantageous for scientists to use a very tiny spacecraft? Use Newton's second law to justify your answer.

STOP & read Science Bite: Shooting for the Stars

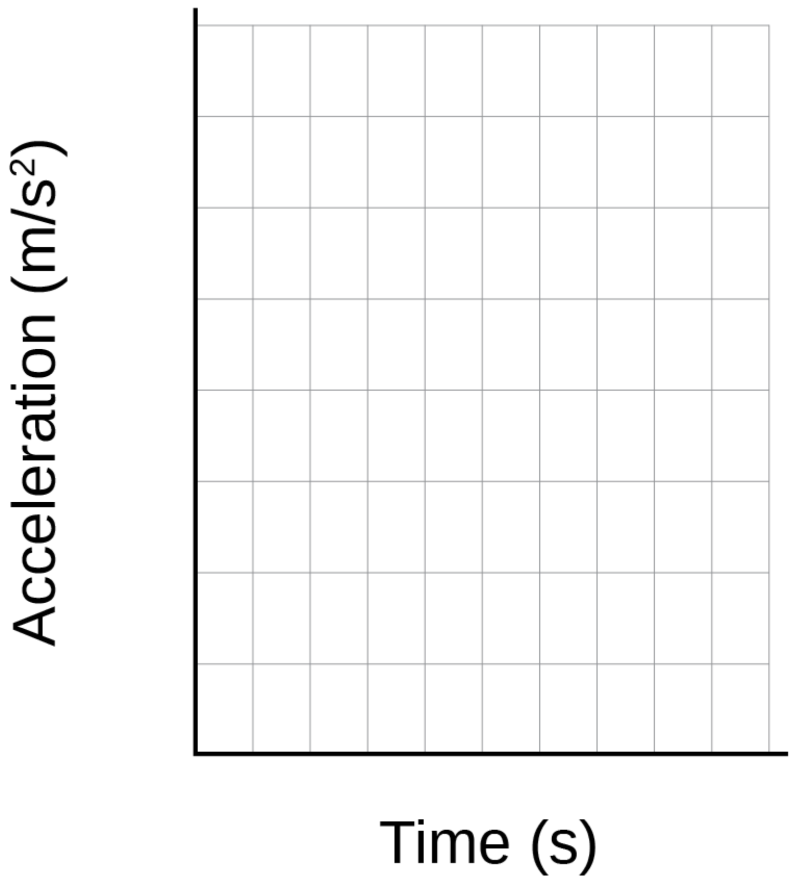
2. The Bite describes the predicted acceleration of the nanocraft. Consider the different ways we can represent this acceleration:

   a. Sketch a graph of velocity *vs.* time of the nanocraft from 0–600 seconds. Recall that the nanocraft's velocity is predicted to increase from 0 to 60,000,000 m/s in ten minutes (600 seconds). Assume the acceleration is constant.



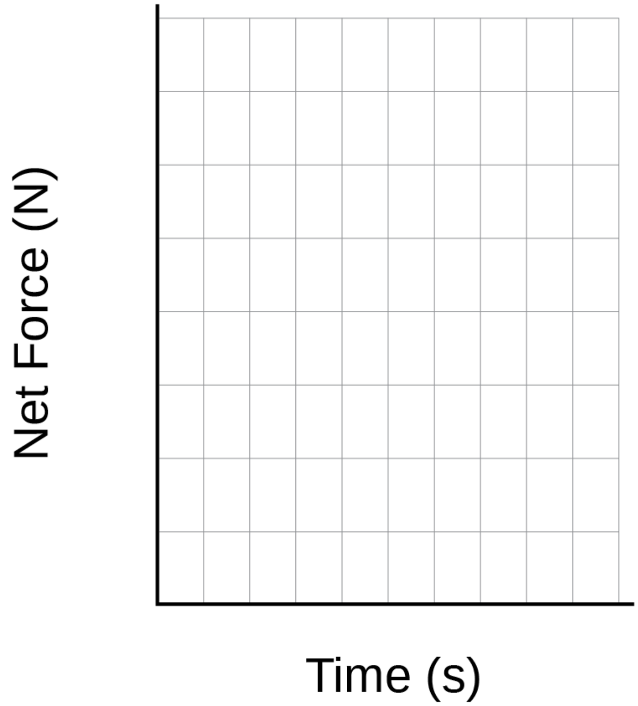
b. Calculate the acceleration of the nanocraft. Show your work.

c. Add values to the x- and y-axes to the graph below and draw an accurate acceleration *vs.* time graph of the nanocraft from 0–600 seconds.

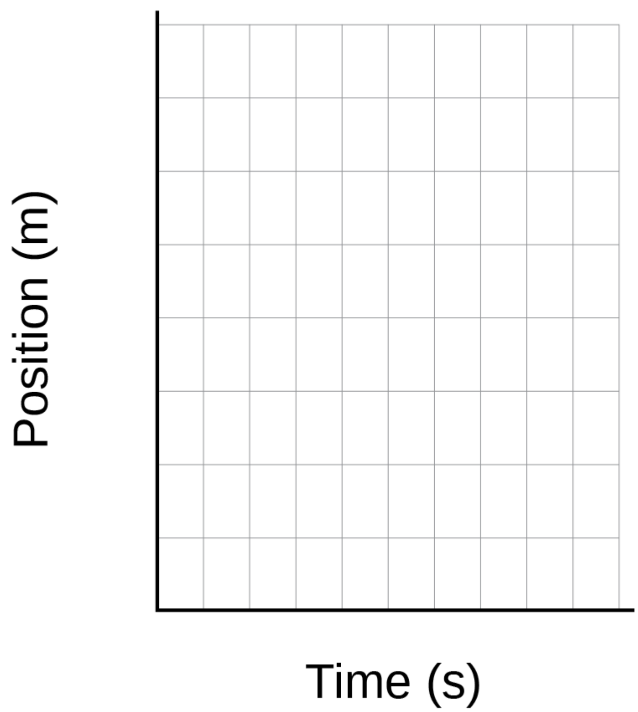


d. What is the net force acting on the 1 gram nanocraft from 0–600 seconds? Show your work.

e. Add values to the x- and y-axes to the graph below and draw an accurate F_{net} *vs.* time graph from 0–600 seconds for the nanocraft.



f. Sketch the shape of the position *vs.* time graph for the nanocraft.



g. Calculate how far the nanocraft would travel in 600 seconds.

3. Based on the descriptions in Bite, draw free body diagrams for the nanocraft in each of the following situations (Assume the force of gravity from the Earth and other objects in space is negligible):

a. When the laser beams are hitting the nanocraft.

b. After the laser beams have stopped hitting the nanocraft, it is traveling away from Earth towards Proxima Centauri.

4. Below are velocity *vs*. time graphs modeling the nanocraft's motion from 0–600 seconds and from 600 seconds to 10 years.

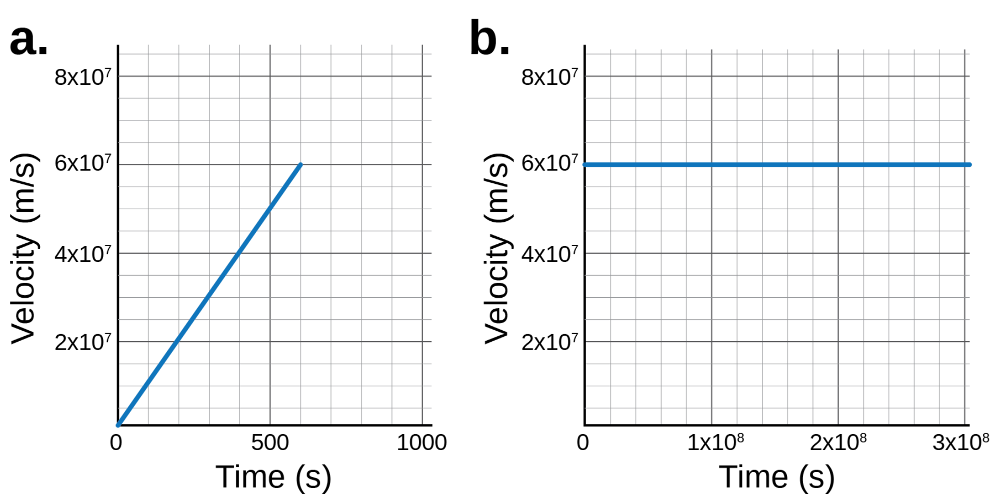


Figure 2. Modeling Nanocraft Motion. Velocity *vs.* time graphs for **a)** the first 600 seconds of the nanocraft's motion; and **b)** the nanocraft's motion from 600 seconds to 10 years.

a. When is there no net force acting on the nanocraft? Explain how you know.

b. Does the nanocraft come to rest when there is no net force on it? Explain how you know.

5. Two students are discussing the relationship between the net force acting on the nanocraft and the nanocraft's velocity. Each student's claim is below.

> **Claim 1:** Because the nanocraft is traveling at 60,000,000 m/s it must have a net force acting on it.
> **Claim 2:** Because the nanocraft is traveling at a constant velocity there is no net force acting on the nanocraft.

Which claim (if either) do you agree with? Explain your reasoning.

6. After the 600 second period of acceleration, how long will it take the spacecraft to reach Proxima Centauri, 4 light years away? Show your calculations or explain your answer. (1 light year = 1×10^{16} meters)

7. Traditional spacecraft are very massive. Would a traditional spacecraft accelerate more or less than the nanocraft if the same force was applied by the lasers? Explain your answer.

8. Suppose scientists have a laser that can provide a force of 100.0 N and a variety of spacecraft of different masses as shown in **Table 1.**

a. Calculate and record the accelerations of the spacecraft in the third column **Table 1**. Show your work below.

b. What trend do you see in the calculated accelerations? Why does that make sense?

Force (N)	Mass (kg)	Acceleration (m/s^2)
100.	1.0	
100.	0.50	
100.	0.25	
100.	0.10	
100.	0.010	
100.	0.0010	

Table 1. Force, Mass, and Acceleration of Theoretical Spacecraft. The force remains constant while the mass changes, what happens to the acceleration?

9. Suppose scientists want a spacecraft to accelerate at a rate of 100,000 m/s^2. They are considering spacecraft with a variety of masses as shown in **Table 2.**

a. Calculate and record the required forces from the lasers in the first column of **Table 2**. Show your work below.

b. What trend do you see in the calculated forces? Why does that make sense?

Force (N)	Mass (kg)	Acceleration (m/s^2)
	2.0	100,000.
	0.50	100,000.
	0.10	100,000.
	0.010	100,000.
	0.0020	100,000.
	0.0010	100,000.

Table 2. Force, Mass, and Acceleration of Theoretical Spacecraft. The acceleration remains constant while the mass changes, what happens to the force?

10. Imagine you are pushing two boxes, one heavy and one light, with a constant force on a frictionless surface.

a. You want the two boxes to reach the same final velocity. Which will you need to push for a longer amount of time, the lighter box or the heavier one? Explain your answer.

b. If the heavy box has twice the mass as the light box, how much time will the heavy box need to be pushed compared to the light box to reach the same final velocity?

c. Why do you think scientists want to create the lightest spacecraft possible to travel to distant star systems? Provide evidence from the tables in your response.

11. Connect to the Big Question. Currently, the most powerful telescopes cannot see exoplanets. Why will the pictures from Breakthrough Starshot be better than the pictures from telescopes we have on Earth? What limitations will the Breakthrough Starshot cameras have (consider how the spacecraft will be moving as it approaches the exoplanet)? Do you think the pictures will be worth the time, effort, and cost? Why or why not?