SF Science Problem Set

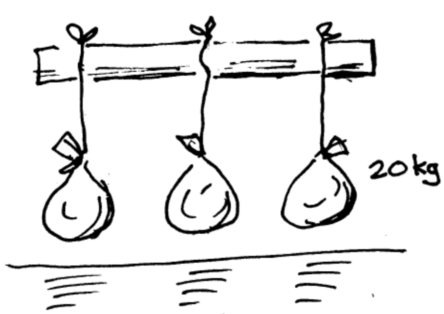
I am developing a set of science problems based on a universe that includes a negative-mass material. Think of it as a study guide or a set of discussion questions for a (very nerdy) book group.

All assumptions are laid out below. If you try these problems and notice mistakes or interesting angles, I'd love to hear them. A link to my book appears after the answers (or at least what I *think* are the answers). Ready? Here we go.

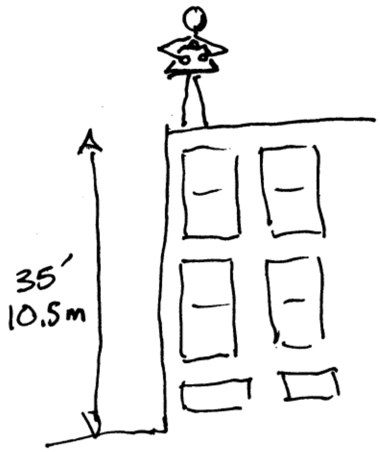
Negative Mass

Conjugate matter has **negative mass**, and for that reason, when left on its own, it accelerates upward into space. Fortunately, even though it has negative weight, it still has **positive inertia**, meaning it accelerates in the direction of the net force. Holding a piece of conjugate matter would feel like holding a bowling ball that wants to float.

Problems

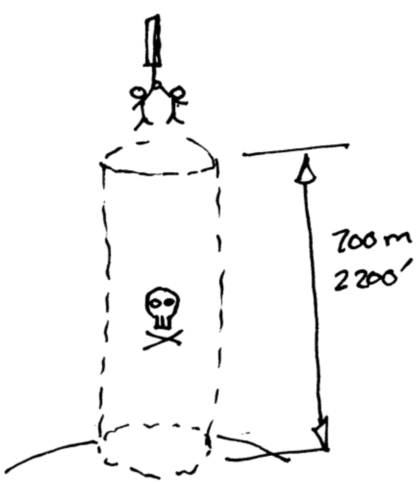


(1) You find a buoy bar made of conjugate lead in a shed in Connecticut. The bar is a cylinder 3 m long and 3.5 cm in diameter. How many kilograms of rock do you need to hang on the buoy bar to give it neutral buoyancy so you can bring it home? If each bag of rocks holds 20 kg, how many bags do you need?



(2) You weigh 70 kg (approximately 155 pounds) and are standing on the roof of your school. You are tightly holding a bag of conjugate matter weighing –67 kg (approximately –143 pounds). The roof is 10.5 m (about 35 feet) above the ground.

(a) What is the fastest *safe* way to reach the ground?
(b) Would it be faster to take the stairs while carrying the conjugate-matter bag?
(c) What about using the elevator?



(3) You and a friend are trying to escape from a desalination plant surrounded by an invisible "curtain of death" extending up to 700 m (about 2,200 feet). You are wearing man-wings that allow you to glide downward. Together, you and your friend weigh 130 kg (approximately 286 pounds), and you have tied yourselves to a T-bird buoy bar weighing –

226 kg. Once you release the buoy bar from the sandbags holding it down, how much time will you have before you reach 700 m? How much time until you reach 3,000 m (where it starts to get cold and dangerous)?

(4) A 2057 T-bird air car with occupants has a gravitational mass equivalent to 10 kg and an inertial mass of about 895 kg. Using four unducted turbofans at maximum power, producing a total of 2,700 N of thrust, how fast can you accelerate from 0 to 96 km/h (60 mph)?

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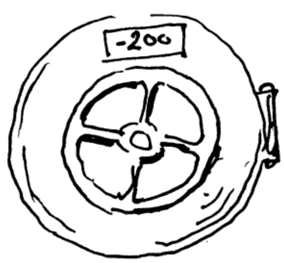
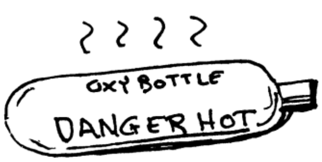
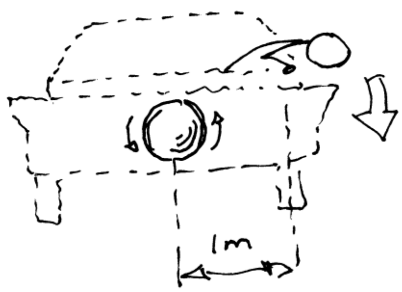
(5) Same situation as above, but now the fans must be angled downward to offset the weight of an additional 80-kg passenger. How does this affect the acceleration?



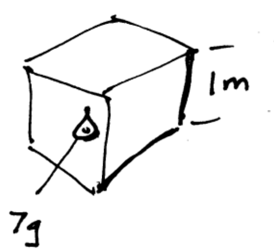
(6) If the rate of food spoilage is halved for every 10°C of refrigeration, how long would a turkey roll with a three-week shelf life at 0°C last at –200°C in a cryo-refrigerator?



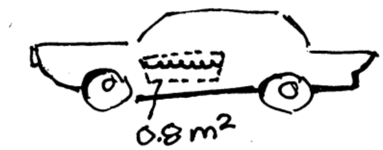
(7) Oxybottles are used in a flying car during emergencies to rapidly increase weight by reacting atmospheric oxygen with a proprietary material inside the bottle. The material is a closely guarded secret, but if you wanted to build such a bottle, what material might you charge an unused oxybottle with? How much of this material would be needed to gain 50 kg of weight by reacting with oxygen?



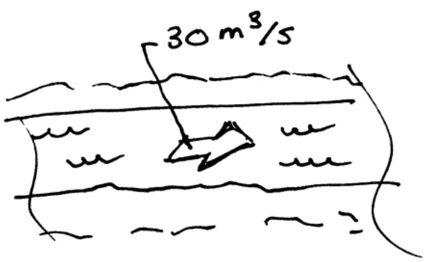
(8) The 2057 T-bird has an inertia sump that helps balance the car when passengers shift around. The sump is a 45-kg sphere of conjugate matter, 30 cm in diameter, suspended on an air cushion at the car's center and spun using rings of electromagnets. How fast must the sphere accelerate to offset the weight of a 65-kg person leaning out the door, with their center of mass 1 m from the sphere's center? If the maximum rotation speed is 10,000 RPM, how long can balance be maintained?



(9) How many cubic feet of air must the water-ballasting system circulate to obtain 45 kg of water in the desert? Assume the air contains 7 g of water per cubic meter. If the condenser fan moves 100 m^3 per minute, how long will this take?



(10) If the wheel well of the T-bird has an area of 0.8 m^2, how much water depth is needed to gain 50 kg of weight?



(11) The Great Salt River has a flow rate of 30 m^3 per second and a salinity equal to that of the ocean. How much salt is produced every minute when this water is distilled to purity?

(12) Cerebral-fogger sunglasses can distract people by emitting a signal at epsilon-range brainwave frequencies. How fast must you blink for the output light to appear continuous?

Answers

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(1) Lead has a density of about 0.0113 kg/cm^3. The volume of the bar is $\pi r^2 h$, where r is the radius and h is the length. So, multiplying the density by the volume gives a negative weight of the bar as approximately 225 kg. About 11 bags of rocks, obtained by dividing the negative weight of the bar by the weight of the bags, should roughly provide equal positive and negative weights between rocks and bar.

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(2)(a) We can figure out how fast you will be going when you hit the ground using this conventional formula:

$$d = v_0 t + 1/2\, at^2 \qquad (1)$$

where d is distance, v_0 is initial velocity, a is acceleration, and t is time.

Because of conjugate mass, we can't assume that the acceleration of the combined weight of you and the conjugate matter is the acceleration of gravity. We can work out the actual acceleration assuming that gravitational acceleration is 10 m/s^2. Here we use:

$$F = ma \qquad (2)$$

where F is the net force acting on the object, m is the inertial mass, and a is the acceleration.

Plugging in the numbers, the net force acting on you is $F = 70 \times 10 - 65 \times 10 = 50$ newtons.

Although the force is limited, it is acting on a high inertial mass of 135 kg, however, so using formula (2) we can work out the actual acceleration:

$$50 = 135a$$

or

$$a = 0.37 \text{ m/s}^2.$$

Now we can find out how fast we will be going when we hit the ground using equation (1):

$10.5 = 1/2 \times 0.37\ t^2$

yielding a time before we hit the ground of t = 7.5 seconds.

And the speed? Simply the time times the acceleration:

$7.5 \times 0.37 = 2.7$ m/s.

Is that safe?

First, let's compare this situation to jumping off the roof with no conjugate matter. Now you will be accelerating at 10 m/s^2, and we can follow the same procedure above to figure out how long it takes to hit the ground:

$10.5 = 1/2 \times 10\ t^2$

t = 4 seconds.

Again, multiplying acceleration by this time yields a speed at which you will hit the ground of 40 meters per second (about 90 mph). Yikes.

Now let's compare it to a normal fall from 1 m, which should be okay if you're careful (safe falling distances are about 1 to 1.5 m):

$1 = 1/2 \times 10\ t^2$

t = 0.44 seconds.

Final speed equals 5.4 m/s.

So, you're golden!

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(2)(b) Stairs are just falling while being interrupted by stair steps. So, taking the stairs with the conjugate matter wouldn't be faster unless you use the handrails to help pull you down.

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(2)(c) It's never faster to take the elevator for short distances. :)

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(3) Your net acceleration will be based on a negative weight of 86 kg or about 9 N. But your total inertial weight is 356 kg. Using formula (2):

$F = ma$

$9 = 356a$

$a = 0.016.$

Using formula (1):

$d = 1/2\ at^2$

$700 = 1/2 \times 0.025\ t^2$

t = 295 seconds (about 4 minutes). You would be going about 6 m/s or about 13 mph when you reach your desired altitude of 700 m — but remember you're wearing huge wings!

For 3000 m the calculation would be:

$3000 = 1/2 \times 0.025\ t^2$

t = 490 seconds (about 8 minutes).

So, you have a scant four minutes after getting to your minimum altitude to get off the buoy bar somehow. At 3000 m you are going about 12 m/s or about 25 mph, a strong breeze where umbrellas and wings are hard to use.

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(4) The force is 2700 N and the inertial mass is 895 kg. Using the same procedure as above:

$F = ma$

2700 = 895a

a = 3 m/s^2.

96 km/h is 26 m/s, so about 8 seconds.

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(5) The 80 kg of weight would require about 800 N of additional downward force to keep the air car in the air. In order to get a downward vector of 800 N, the 2700-newton force would need to be directed downward by about 17 degrees from horizontal. This is obtained by using trigonometry to do a vector decomposition, yielding the equation:

$\sin(\theta) \times 2700 = 800$

$\theta = 17$ degrees.

The reduction in the horizontal force would be cos(17°) or about 0.96, bringing the horizontally directed force of 2700 N to 2580 N, or increasing the acceleration computed above to about 8.3 seconds. No big deal.

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(6) Very roughly, there are 20 increments of 10 °C reduction, so 20 × three weeks, or basically forever.

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(7) You want the bottle to start out as light as possible so as to maximize the effect of the accumulated oxygen while not increasing the weight of the car too much. So, an attractive material would be hydrogen, which is very light and reacts with oxygen to form H_2O, which is about 88% oxygen by weight. But this reaction is likely to be exothermic, making steam that might be hard to contain, so maybe the next better choice might be sodium, which reacts readily with atmospheric oxygen to form sodium oxide, which is about 70% oxygen by weight. Using sodium would require a weight of at least 71 kg of sodium in the oxybottle.

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(8) This is a torque problem, but otherwise very similar to the other acceleration problems. The torque caused by the person is 1 m·N. So, the sphere needs to accelerate to produce a countervailing torque equal to this amount. The moment of inertia I of the sphere is somewhere between $I = 2/5\ mr^2$ for a solid sphere and $I = 2/3\ mr^2$ for a thin spherical shell, so somewhere between 0.4 and 0.7.

For rotational acceleration, $F = ma$ becomes $\tau = I\alpha$, where τ is torque and α is angular acceleration.

So:

$1 = (0.4–0.7)\ \alpha$

The angular acceleration is somewhere between 2.5 and 1.4 radians per second, or somewhere between 23 and 13 RPM per second.

At this acceleration, balance can be maintained for between 7 minutes and 12 minutes.

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(9) About 6400 m^3 of air is needed, or about 64 minutes would be required to obtain ballast from the air.

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(10) The weight of water is about 1 g/cm^3, and so 50 kg would require 50,000 cm^3 or about 0.05 m^3 of water. So, over an area of 0.8 m^2, this would require a height of about 6 cm.

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(11) The ocean has about 35 kg of salt per cubic meter. So, this would mean about a thousand kilograms per second, or 60,000 kg per minute, of salt would need to be removed. That's a lot of salt. Boatloads.

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(12) Epsilon frequencies of the human brain are about 0.5 Hz. So, if you can time it right and blink at this frequency, the signal should appear continuous and not affect you. If you're close to this frequency, you will still alias the signal and will probably move it outside of the relevant frequency range to make it ineffective.

Problem set based on Outsider: Sometimes it's home that finds you, available at Amazon in paperback and Kindle.