

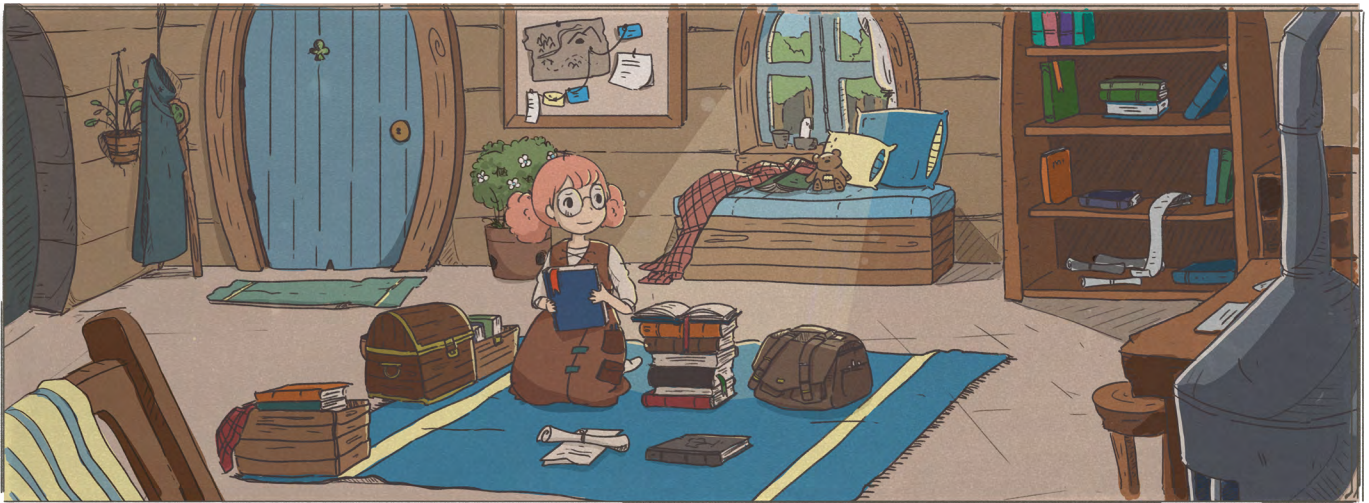


Name: \_\_\_\_\_

Date: \_\_\_\_\_ Period: \_\_\_\_\_

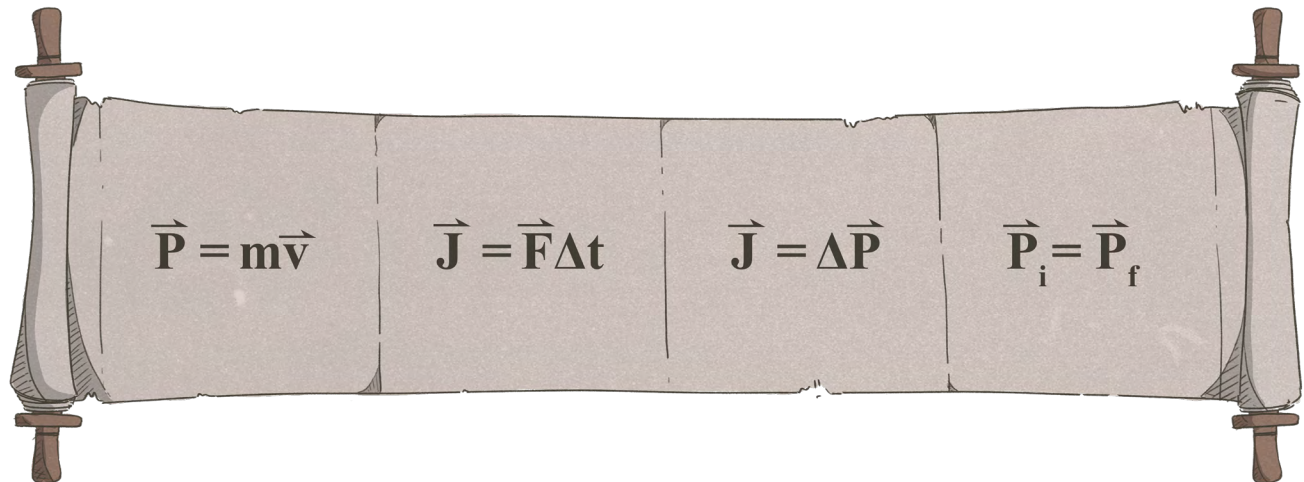
# MOMENTUM

## A PHYSICS STORY



It's time! This is the year! You're finally going to do it! The king's adventurer finally died a horrible, grisly death and now they're holding tryouts for his replacement! Yes, this will mean you'll have to leave your cozy woods cottage, which is a definite downside, but you've been planning this for years. You have charts and graphs and contingency scenarios outlined on scraps of parchment pinned to every wall, and you've thought it through from every angle. You know you can do it. Plus, it's not like you can't bring your books and notes with you.

You narrow your collection down to just the essential 47 books (mostly reference tomes, but a few good adventure stories, just in case you need inspiration), pack them all into waterproof trunks, stack them in your wagon, and set off for the capital.





On the way, you practice, thinking through every possible science calculation you might need. Sure, the adventurers of the past have all been heroic fighters (although, usually the more heroic they were the shorter their time in office was--Hildegard the Insanely Brave was famously so heroic she only lasted 6 minutes before being eaten by the dragon whose jaws she had clambered into), but you are sure that you could be an adventurer, too, just a different kind. Sure, you've never left your little village and to be honest you barely leave your house (your favorite shoes are your fuzzy slippers with built-in heat packs), but you've thought it through and you're pretty confident you can do this.

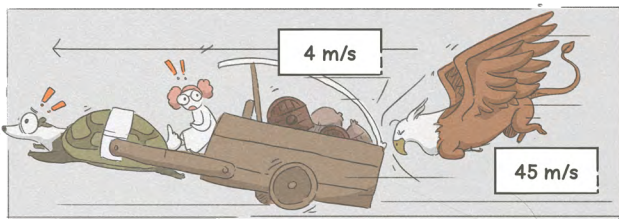


- #1 While riding your wagon through the sun-dappled dirt road, the spring-green leaves overhead rustling in the warm breeze, you contemplate your turtle-badger as it pulls you and your cart along. It looks like it has a mass of around 135 kg, and you estimate your speed is around 4 m/s. How much momentum does the turtle-badger have?





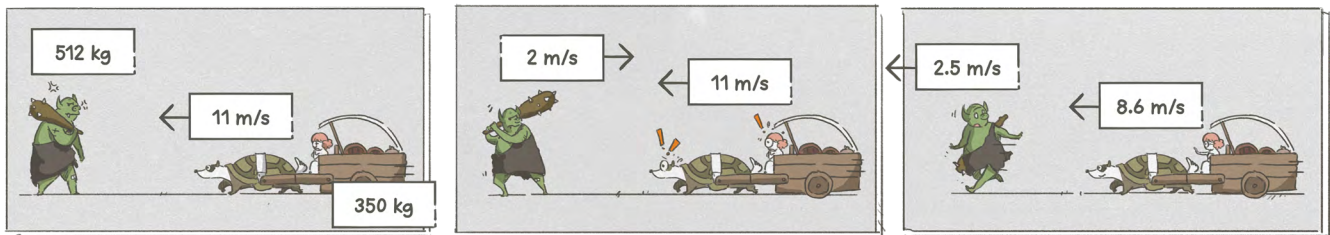
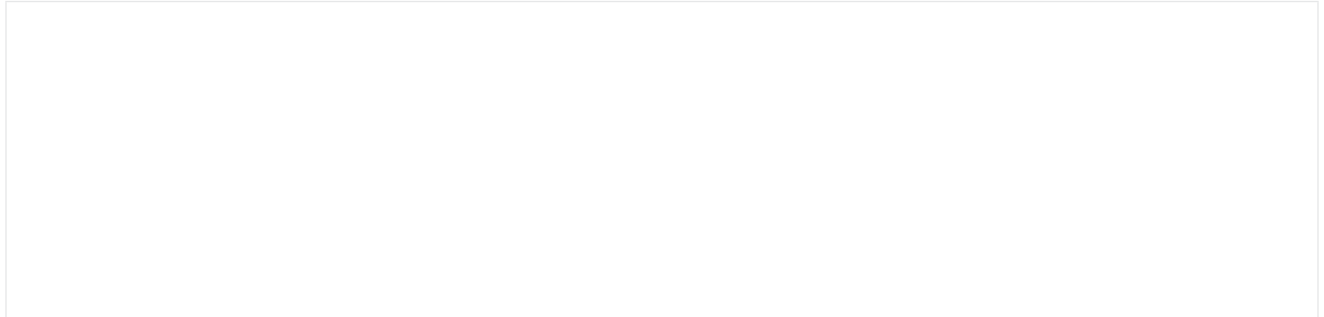
#4 Probably, though, if a griffin were attacking (and you don't really know, this is just a guess, since you've never been attacked by a griffin before) it would be going faster. Maybe the griffin (165 kg) were rocketing up from behind, travelling at 45 m/s when it collided with the wagon (350 kg, still traveling at 4 m/s), landing on it and shoving it forward. How fast would the wagon, griffin, and turtle-badger be going after that collision?



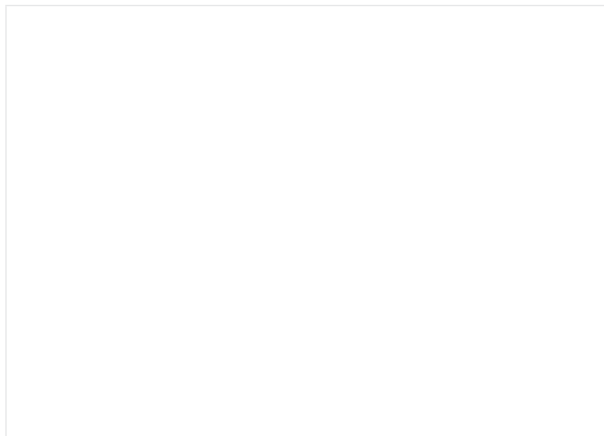
#5 Or, and this is a really exciting thought, what if you saw the griffin (165 kg) coming, so you stood up (with the wagon still moving at 4 m/s), grabbed your long walking stick, braced yourself against the wagon (350 kg), and took a huge swing at the griffin? Maybe it was flying up towards you at 18 m/s, and after you hit it, it went flying backwards at 3 m/s. This would definitely propel you and your wagon and the turtlebadger forwards. How fast would you be going after that?



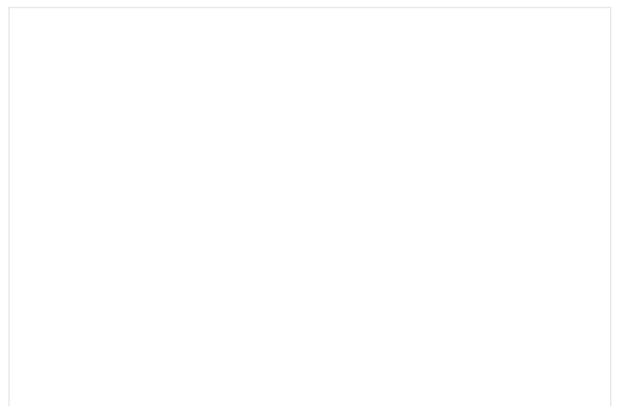
#6 What if, instead of coming from behind, you see some dastardly threat up ahead? Maybe you and your wagon and the turtle-badger (total mass = 350 kg), are galloping forwards at 11 m/s, and you see a club-wielding troll up ahead (mass = 512 kg). If it's just standing there looking menacing and you crash into it, how fast would you and the troll and the turtle-badger and the wreckage of your wagon be going after you got all tangled up together?



#7 What if, instead, the troll (512 kg) was striding towards you at 2 m/s, preparing to swing its club at you? If again you (350 kg) barrel into it going 11 m/s, in what direction and how fast would you all be going after you collided?



#8 Or maybe the troll would try to run away. You'd hope you could avoid hitting it if that were the case, but what if it were running away at 2.5 m/s and you (350 kg) barreled into it going 8.6 m/s? If you all collided, how fast would you be going at that point?





These daydreams are so riveting that the time flies by, and soon you find yourself in the capital. The city is absolutely packed. Throngs of humans, elves, centaurs, dwarves, and goblins fill the streets, pushing and weaving in between limestone spires and green copper domes. You wonder if it's always like this, or if everyone is here for the festival. You notice, though, that the banners are being taken down, the flags representing people's favorite champions are being reverently folded. Noisemakers and novelty tunics are being sold at half price. This does not feel like the beginning of a festival, it feels like the end.



Worried that your daydreams took longer than you realized, you ask a passing goblin. She pats your turtle-badger on the nose--he closes his eyes and hums--as she tells you that the trials were cancelled. The king has already picked a new adventurer: Armband the Unstoppable, who was the last adventurer's apprentice. A storm of emotions passes through you: utter devastation at the loss of your dreams, anger that the king would just change the rules like that, and confusion that anyone would be named Armband.

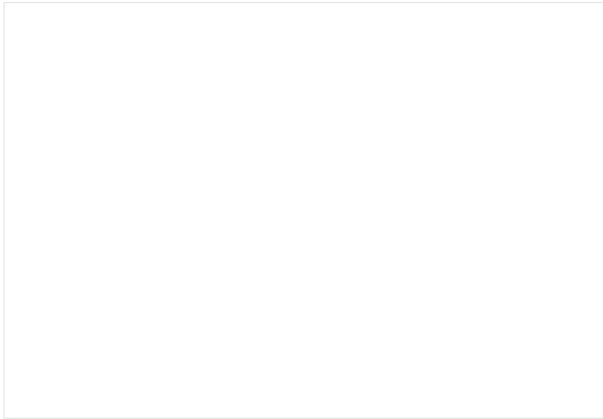
You wander the streets disconsolately for a few minutes, not wanting to just go back home, now that you've come all the way here. Possible options run through your mind. You could request an audience with the king, you could lead a protest, you could kidnap this Armband and any future picks of the king until he agrees to hold the trials. The last idea in particular appeals to you, but as you mull over the logistics of such a kidnapping, you get an even better idea. You'll simply out-adventure him. Every adventure he goes on, you'll find out what it is and complete it first.

You give an excited hop. This will be like an even better version of the trials. Harder, and without all the crowds and spectators and other competitors. Perfect all around, really. You're not totally ruling out kidnapping him, though.

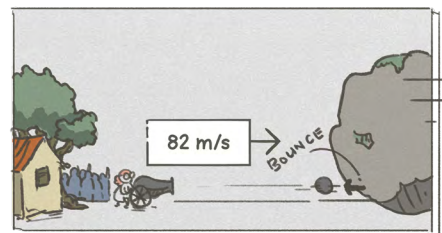
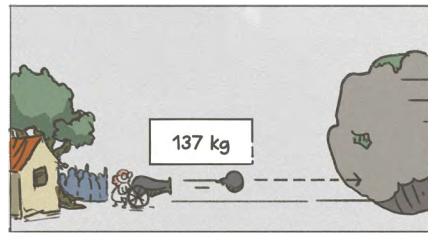
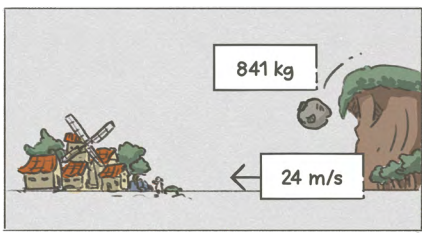
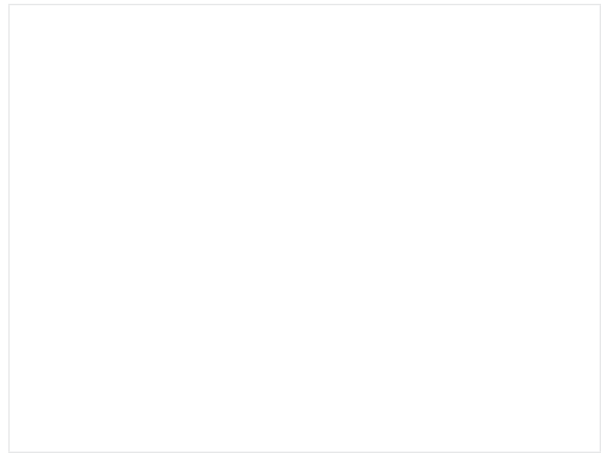
Finding out where Armband lives and following him on his adventures ends up being even easier than you'd thought...



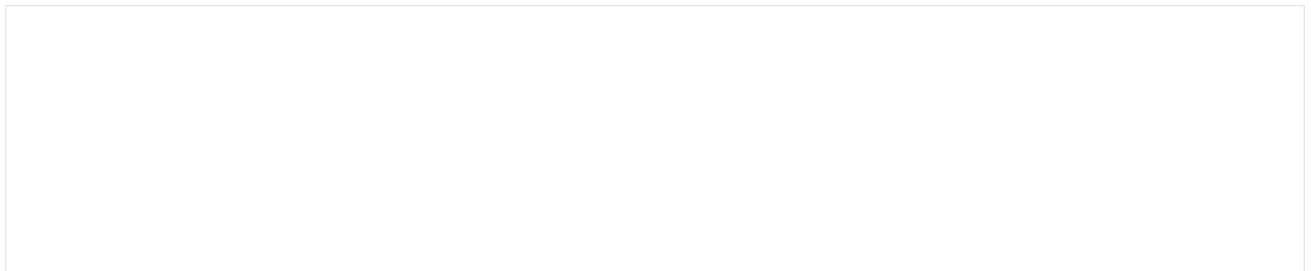
#9 A bolder balanced precariously on a cliff above a village dislodges in the bi-weekly earthquake caused by the granite crab miners. It has a mass of 841 kg and rapidly picks up speed to 24 m/s. You have 15 seconds to stop it as it crosses some flat ground before it hits the village. How much force would you have to exert on it to stop it in time?



#10 You and the turtle badger are strong, but you're not that strong. You consider instead firing a projectile straight at it to try to stop it. You find a local canon ball maker who has a canon ball of mass 137 kg. How fast would you have to shoot it at the boulder in order to have them both stop dead in their tracks?



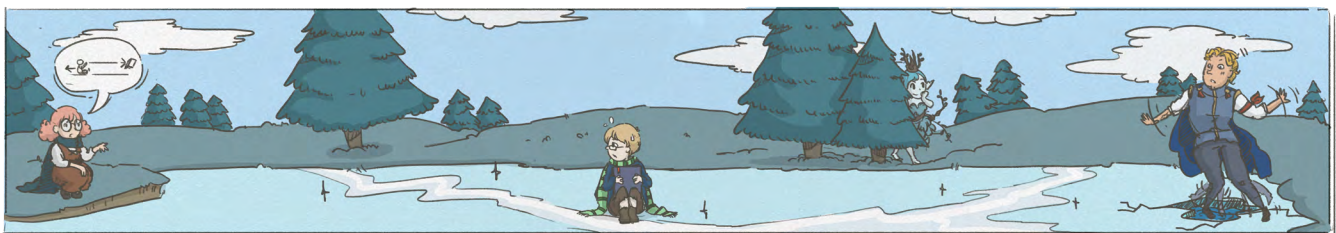
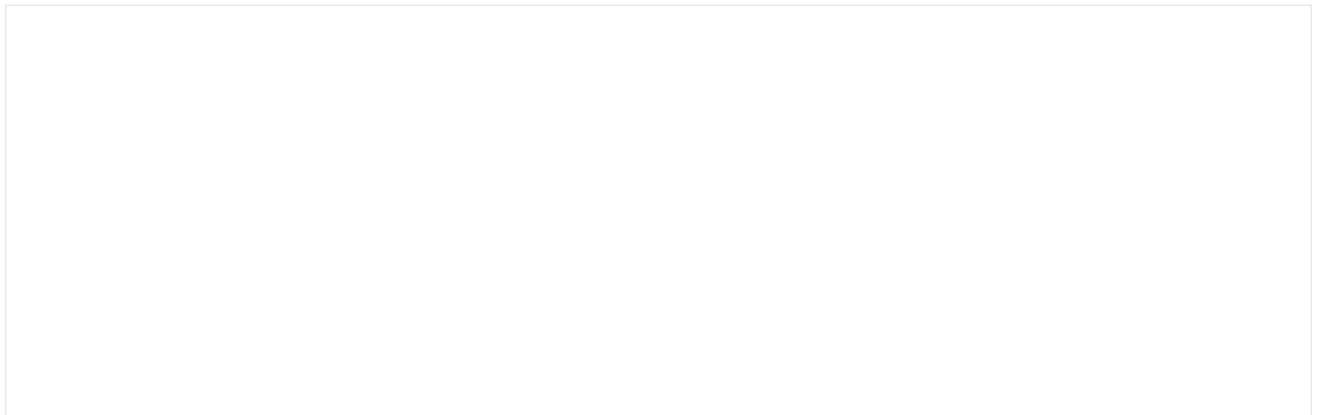
#11 Even this seems unrealistic. But you have yet another idea. You ask the canon ball maker to create a ball that bounces, so that when it hits the boulder it will bounce backwards at exactly the speed it came in at. You fire it towards the boulder at a speed of 82 m/s. It hits the boulder and bounces backwards at exactly the same speed. How much mass would the bouncing canon ball have in order to exactly stop the boulder?





When Armband arrives at the village, he finds the villagers already cheering and tossing you in the air.

- #12 On your way back from your victory (you're following Armband at a distance of about 50 ft, just to watch in case he tries anything adventurous) you see a child stuck out in the middle of an icy lake. They explain that while they were walking across the lake they angered the dryad who lived there, who responded by making the lake completely frictionless. They are trying to walk, but the ice is now far too slippery and they keep falling. Armband steps gallantly onto the ice to try to rescue the child, but immediately breaks through. You notice the child is carrying a heavy book--which you deeply approve of. It looks like the child has a mass of about 38 kg, and the book has a mass of 4 kg. You tell the child to throw the book as hard as they can away from them. They throw it with a speed of 7 m/s. With what speed do they go flying backwards to safety?

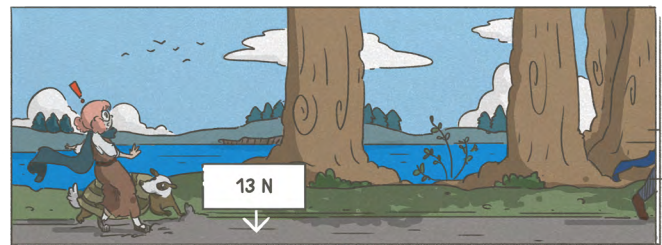








- #16 You skip along after him at  $5.4 \text{ m/s}$ , then remember you're supposed to be secretly following him and slow to  $1.3 \text{ m/s}$ . If your mass is  $54 \text{ kg}$ , what was your change in momentum? (Assume that walking towards Armband is the positive direction.)



- #17 If you exerted a force of  $13 \text{ N}$  against the ground to slow yourself down, how long did it take you to achieve your new speed?



Armband quickly complains to the king and you and your turtle-badger are arrested and thrown in prison.

A prison cell can't hold you, you think. You test every brick, looking for weaknesses; you pull yourself up to the tiny narrow window and jiggle every one of the bars. You and the turtle-badger push and pull against the cell door, testing the hinges. But you find no way out.

Momentarily stumped, you sit on the floor, thinking.



#18 Eventually, when no more ideas occur to you, you start pacing. Your cell is 3 m by 4 m, and you (54 kg) walk back and forth the longer way at 2 m/s. The turtle-badger watches you, sitting at the far right side of the cell, cleaning her claws. You think of walking towards the turtle-badger as the positive direction, and the other direction as the negative direction.

- When you reach the side with your companion and turn around, what is your change in momentum?
- When you turn at the far side, what is your change in momentum?
- If it takes you exactly 5.3 seconds to execute each turn, what magnitude of force do you use to make that turn?



#19 You (54 kg) keep trying to think of a way out. Maybe you could break the door. You imagine walking with a momentum of  $250 \text{ kg}\cdot\text{m/s}$  and then putting on a burst of speed, exerting a force against the ground of 60 Newtons for 2.5 seconds.

- What would your new momentum be?
- What would your new speed be?



After running the numbers, this seems far-fetched to you. And, by the turtle-badger's expression, it seems far-fetched to him, too. You begin testing all the bricks in the cell again. One of them does seem to have something off about it, but you can't quite figure out what it is. Before you can investigate more, though, you hear someone coming down the hall.

The cell door swings open and you bolt for it, but before you reach it, an elderly man is thrown in. The soldier outside slams the door shut, locks it, and stomps off, whistling offkey.

You look at your new cell mate, and, to your surprise, it's the king. He looks embarrassed to be there.



He tells you that Armband the Unstoppable has taken over the kingdom. The king had known he was ambitious, and had hoped that making him an adventurer would have been enough to satisfy him, but apparently with you showing up and out-doing him all the time he felt like he needed to take things further.

You feel annoyed that the king is somehow implying this is your fault, when he's the one who changed the rules at the last minute, but you feel like it would be impolite to point that out, so instead you tell the king not to worry, you were just about to break out of this cell. You can escape together and go take back his kingdom. You point out the strange brick you'd noticed.

The king nods, goes to the brick, pulls it partly out, twists it, and a secret passageway opens up.

"I include escape routes in all my cells, just in case this ever happens."

"Do prisoners ever break out?" you ask.

"Pretty frequently," he says with a shrug. "But, I wouldn't want to keep anyone in here too long, anyway."

You start down the tunnel, but the king doesn't follow you. You turn back and ask him if he's coming.

"Armband has many supporters. I'm not sure it's possible to overthrow him at this point."

"Easy," you say. "He's an adventurer. We'll give him an adventure."





You find your wagon where you left it; surprisingly no one stole your books. You find your anxiety mounting as you approach the central square of the capital. Of course it would come down to a public display. The thing you dreaded most about the competition. But, if this is what you have to do, you're going to do it.

You stack every one of your books up, a couple of books wide, making a narrow platform. Then you climb to the top, and address the crowd that has gathered, curious. You issues a challenge that no adventurer could pass up. The Spring Ricochet, a furious competition where hundreds of rhinorams compete, head-butting one another, attempting to knock each other out of the center of the field. It's long been a tradition for adventurers to try to cross the field while this is going on, and handily it's only a few miles from the capital.



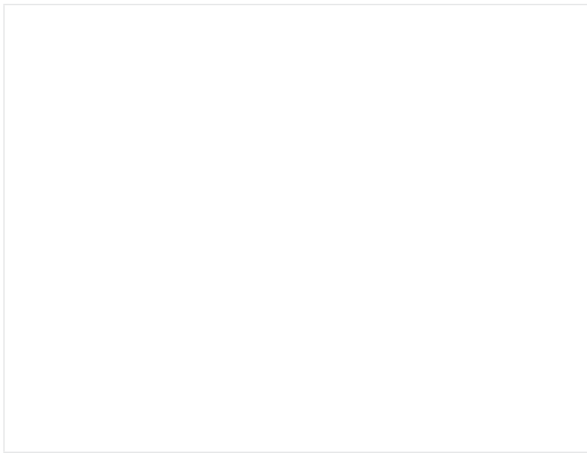
Word carries quickly, and it's not long before you and Armband the Unstoppable stand at the edge of the field, watching hundreds of enormous rhinos with wide, ram-like horns, sprinting across the field in all directions, head-butting each other. First one to make it across wins. You try not to think about the close to a thousand onlookers, all staring at you as the starting horn blasts and Armband leaps confidently into action.

He dodges a few, but is pretty quickly wiped out by an unanticipated rhino sailing in from the left. He's back on his feet in an instant, but another determined rhino from the right tramples him.

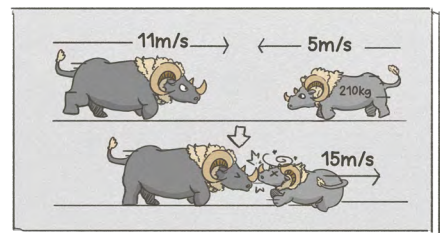
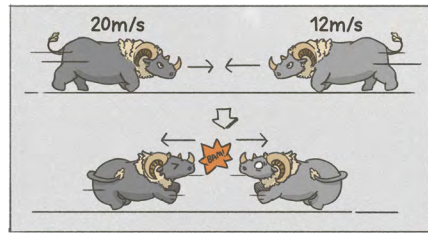
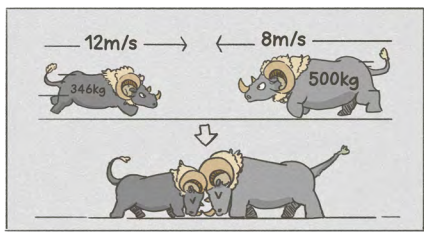
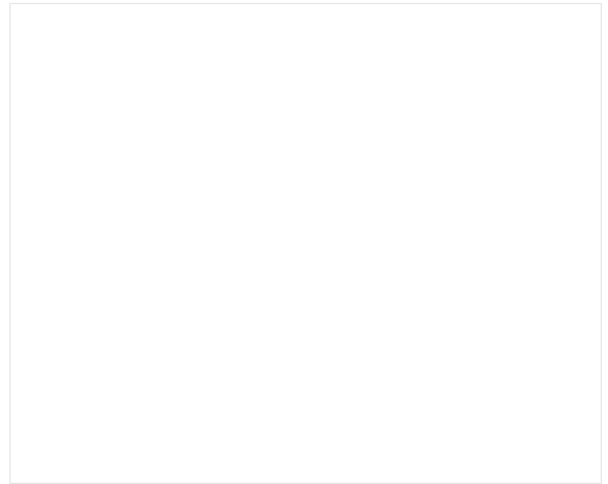




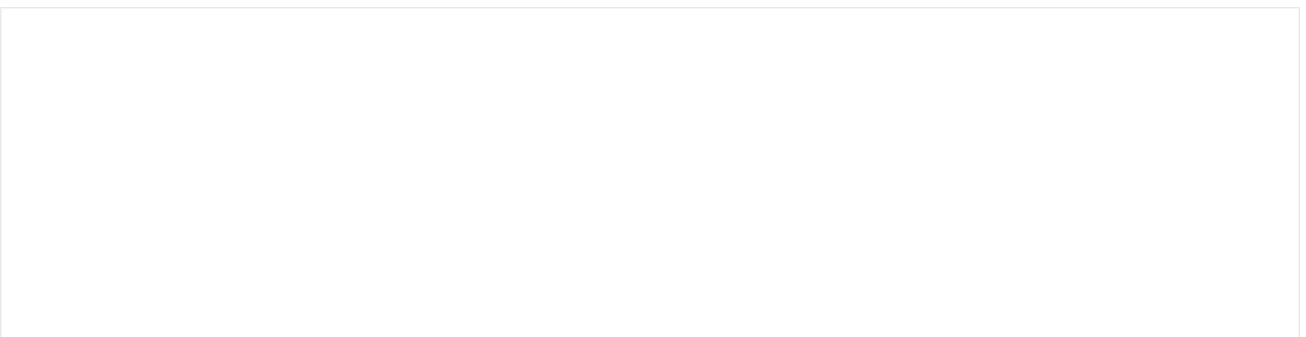
#20 You watch, carefully noting the positions, masses, and velocities of all the rhinorams. A 500 kg rhino comes from the right at 8 m/s, heading for a much smaller, 346 kg rhino from the left. The smaller rhino is going much faster, though, about 12 m/s. If they collide and stick together, which direction will they be going?



#21 Two equally-sized rhinorams collide head-on, and one of them bounces backwards with a speed exactly double its initial speed of 20 m/s. If the other rhinoram had a speed of 12 m/s, with what speed will it be going after the collision?



#22 A huge, 470 kg rhinoram barreling along at 11 m/s to the right collides head on with a smaller, 210 kg rhinoram travelling only 5 m/s to the left. The smaller rhinoram flies backwards at 15 m/s. With what speed and in what direction does the larger rhinoram travel after the collision?





he crowd is shouting at you to go, but you're still sitting there thinking, watching, as Armband struggles further and further across the field. He's over halfway now. He keeps getting whacked but he does seem to be unstoppable. Finally, you take a deep breath, and you step out into the field.

Rhinos fly everywhere around you as you calmly walk, taking a step to the right, then a few steps to the left, then ducking as a bellowing rhino flies over your head, its legs kicking in the air.

The crowd is at first laughing, then silent as you reach the center of the field. When you are  $\frac{3}{4}$  of the way they start to cheer, and when you pass Armband, or rather as he passes you, struggling to escape from the rhinorams horns as he's carried along, they go crazy.

You take a few more steps, dodging one last rhino, and you're across.

Armband finally makes it off the field, but the crowd is cheering, lifting you up. They carry you past him, picking up the king along the way to the castle.

The king regains his throne and as a token of gratitude appoints you King's Adventurer. He also forgives Armband, giving him some glamorous but not too important roles in the kingdom.

You, with your trusty turtle-badger, enjoy a long and thoughtful tenure as the most careful and planning-oriented adventurer in the position's history.







# ANSWER KEY

## MOMENTUM (A physics story)

(Units for momentum can be written  $\text{kg}\cdot\text{m}/\text{s}$  or  $\text{N}\cdot\text{s}$ ) Round all answers to the tenths place.

1.  $540 \text{ N}\cdot\text{s}$
2.  $215 \text{ kg}$
3.  $2.7 \text{ m}/\text{s}$
4.  $14.8 \text{ m}/\text{s}$
5.  $13.9 \text{ m}/\text{s}$
6.  $4.5 \text{ m}/\text{s}$
7.  $3.3 \text{ m}/\text{s}$  in the same direction your wagon was traveling initially.
8.  $5.0 \text{ m}/\text{s}$
9.  $1,345.6 \text{ N}$
10.  $147.3 \text{ m}/\text{s}$
11.  $123 \text{ kg}$
12.  $0.7 \text{ m}/\text{s}$
13. The change in momentum of one was  $28 \text{ N}\cdot\text{s}$ , and the change in the other was  $-28 \text{ N}\cdot\text{s}$  (the sign depends on whether you chose the direction the book travels in to be the positive direction or the negative direction- either way is correct.)
14.  $10.8 \text{ N}$
15.  $-723.8 \text{ N}\cdot\text{s}$
16.  $-221.4 \text{ N}\cdot\text{s}$
17.  $17 \text{ s}$
18.
  - a.  $-216 \text{ N}\cdot\text{s}$
  - b.  $216 \text{ N}\cdot\text{s}$
  - c.  $40.8 \text{ N}$
19.
  - a.  $400 \text{ N}\cdot\text{s}$
  - b.  $7.4 \text{ m}/\text{s}$
20.  $0.2 \text{ m}/\text{s}$
21.  $28 \text{ m}/\text{s}$
22.  $6.5 \text{ m}/\text{s}$  to the right