

Solve the Jump

The Season One physics workbook

Eleven stunts on an electric unicycle across St. Louis. One chapter for every stunt. Before each one, you do the math and make your prediction. On the night, the live numbers settle it.

NAME _____

CLASS _____

Solve it. Don't try it.

WHEEL-9BRT.PAGES.DEV/SOLVE

FOR STUDENTS

Every chapter starts with a real stunt from the season and the question underneath it. Read the idea, follow the worked example, then do your own problems. Before the episode, fill in your predictions. When it happens, write down the real numbers and see how close you got.

Every problem has a level: ★ **Rookie** needs no trig, ★★ **Pro** uses the physics formulas, and ★★★ **Engineer** problems are puzzles with more than one way in. Some give you clues instead of numbers, so you have to figure out the inputs first.

The stunts are done by a professional rider, with engineers, permits and safety systems. Your job is the math. Never try them.

FOR TEACHERS

Chapters stand alone and can be used in any order. Most work in a 40 to 50 minute class. Levels are marked on each chapter; the grade 6 to 12 chapters need no trigonometry. The answer key is a separate download at wheel-9brt.pages.dev/solve. Every problem is checked in code against the key.

Numbers marked "suppose" or "say" are round numbers picked for the math. Chapter 01 uses real 2024 data for Metro St. Louis buses. Encourage students to challenge every assumption.

THE CHAPTERS

★	The Ramp Kit · Why does every jump this season use the same two ramps?	Start here
00	Také Style · Does standing side-on really use less energy?	Grades 6 to 12
01	The Empty Bus · When is a bus the cheapest way to move people, and when would a Lamborghini be cheaper?	Grades 6 to 12
02	79 in One · What's the shortest route that touches all 79, and does the battery make it?	Grades 6 to 12
03	The Keg Line · How fast at the lip to clear ten kegs?	Grades 9 to 12
04	Jump the Zamboni · How high does the jump have to go, and can a tire grip ice hard enough to get there?	Grades 9 to 12
05	The Parade · Why is it harder to balance slow than fast?	Grades 6 to 12
06	The Bend · How far do you have to lean to hold a turn at speed?	Grades 9 to 12
07	The Spirit · Why does going twice as fast take eight times the power?	Grades 9 to 12
08	Art Hill · Why do big jumps land on a down-ramp?	Grades 9 to 12
09	Center Stage · If you throw a ball while you're riding, how fast is it really going?	Grades 6 to 12
10	The Wash Ave Gap · There's no second try. What is the window?	Physics

NUMBERS YOU'LL USE

Gravity	$g = 9.8 \text{ m/s}^2$ (32.2 ft/s ²)
Speed	1 mph = 0.447 m/s · 1 m/s = 2.237 mph
Length	1 m = 3.281 ft · 1 ft = 0.3048 m · 1 in = 2.54 cm · 1 mile = 1,609 m
Energy	1 Wh = 3,600 joules
Air	density about 1.2 kg/m ³
Your calculator	Set it to degrees, not radians, before any sin, cos or tan.

HOW TO SOLVE ANY PROBLEM IN THIS BOOK

1. Write down what you know, with units.
2. Pick the formula that connects them.
3. Convert to matching units (usually meters and seconds).
4. Plug in and solve.
5. Ask: does this answer make sense? Would you bet on it?

EVERY FORMULA IN THE SEASON

Ramp kit	Gap = $\text{speed}^2 \times \sin(2 \times 20^\circ) \div g$, with both lips at the same height
Ch 00	Drag force = $\frac{1}{2} \times \text{air density} \times \text{drag coefficient} \times \text{frontal area} \times \text{speed}^2$
Ch 01	Cost per rider per mile = cost to run the vehicle one mile ÷ riders on board
Ch 02	Energy needed = route miles × watt-hours per mile
Ch 03	Distance = $\text{speed}^2 \times \sin(2 \times \text{ramp angle}) \div g$
Ch 04	Peak height above the lip = $(\text{speed} \times \sin(\text{ramp angle}))^2 \div (2 \times g)$
Ch 05	A feedback loop: sense the lean, correct, repeat
Ch 06	$\tan(\text{lean angle}) = \text{speed}^2 \div (\text{turn radius} \times g)$
Ch 07	Power to beat drag = $\frac{1}{2} \times \text{air density} \times \text{drag coefficient} \times \text{frontal area} \times \text{speed}^3$
Ch 08	Downward speed at landing = $\sqrt{(2 \times g \times \text{height fallen})}$
Ch 09	Ball speed over the ground = wheel speed + throw speed (thrown backward: wheel speed – throw speed)
Ch 10	Gap = $\text{speed}^2 \times \sin(2 \times \text{ramp angle}) \div g$, with both lips at the same height

WHERE THE NUMBERS COME FROM

Chapter 01: Metro St. Louis bus costs and riders, National Transit Database 2024 agency profile; bus prices, Brookings (2025); SUV price, Kelley Blue Book (2026 model). Everything else is a stated assumption for the exercise.

The Ramp Kit

Why does every jump this season use the same two ramps?

THE SETUP

Every jump this season uses one ramp kit: a launch ramp and a landing ramp, built to the same 20° angle by the same crew, set at the same height and trucked to every venue. Only two things change from stunt to stunt: the gap, and the speed at the lip.

THE IDEA

When the lip and the landing are the same height, the wheel lands at the same angle it took off, and the top of the arc sits exactly halfway across the gap. That makes every jump predictable: practice the exact setup in a parking lot until the speed at the lip repeats, then take it to the venue. The season climbs a speed ladder, a little faster each jump, up to 40 mph for the finale.

THE PHYSICS

Gap = $\text{speed}^2 \times \sin(2 \times 20^\circ) \div g$, with both lips at the same height

WORDS TO KNOW

Lip

The top edge of the launch ramp, where the wheel leaves the ground.

Landing zone

The stretch of the landing ramp that's safe to touch down on.

Speed ladder

The plan to go a little faster each jump, proving each step before the next.

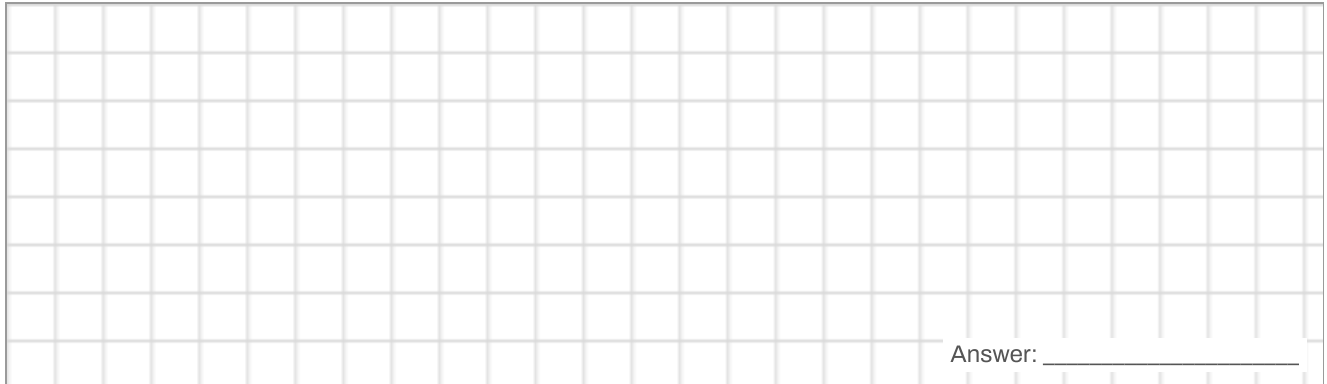
Worked example. Make the kit's table: what speed at the lip clears each gap?

1. 10 ft = 3.05 m → $\sqrt{(3.05 \times 9.8 \div 0.643)} = 6.82 \text{ m/s} = 15.2 \text{ mph}$.
2. 13 ft = 3.96 m → $\sqrt{(3.96 \times 9.8 \div 0.643)} = 7.77 \text{ m/s} = 17.4 \text{ mph}$.
3. 20 ft = 6.10 m → $\sqrt{(6.10 \times 9.8 \div 0.643)} = 9.64 \text{ m/s} = 21.6 \text{ mph}$.
4. 26 ft = 7.92 m → $\sqrt{(7.92 \times 9.8 \div 0.643)} = 10.99 \text{ m/s} = 24.6 \text{ mph}$.
5. 33 ft = 10.06 m → $\sqrt{(10.06 \times 9.8 \div 0.643)} = 12.38 \text{ m/s} = 27.7 \text{ mph}$.
6. And the finale: 40 mph flies about 69 ft.

YOUR TURN

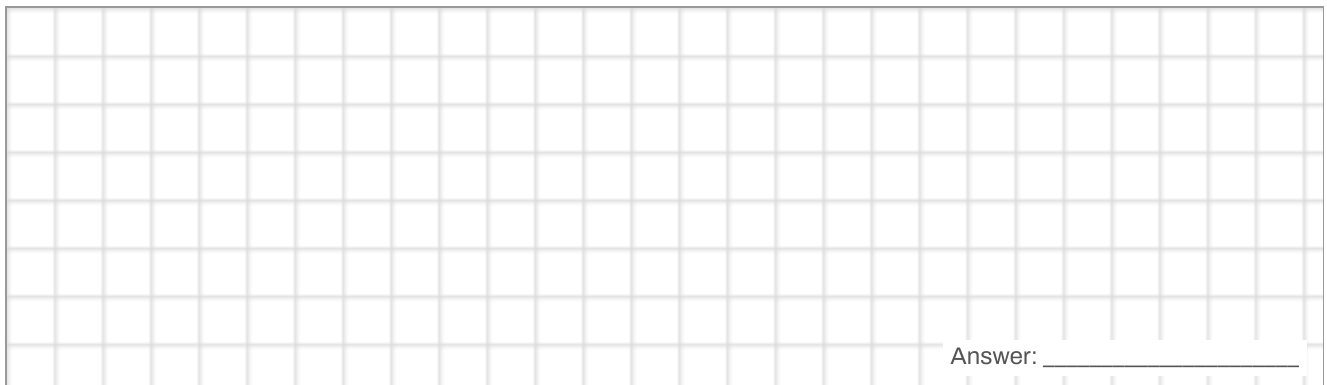
Show your work. Round to the same number of decimal places as the numbers you're given.

- 1** **★ ROOKIE** Clue: a training video runs at 60 frames per second. The wheel crosses a 10-foot chalk box in 10 frames. How fast is it going, in feet per second and in mph? (1 mph = 1.467 ft/s.)



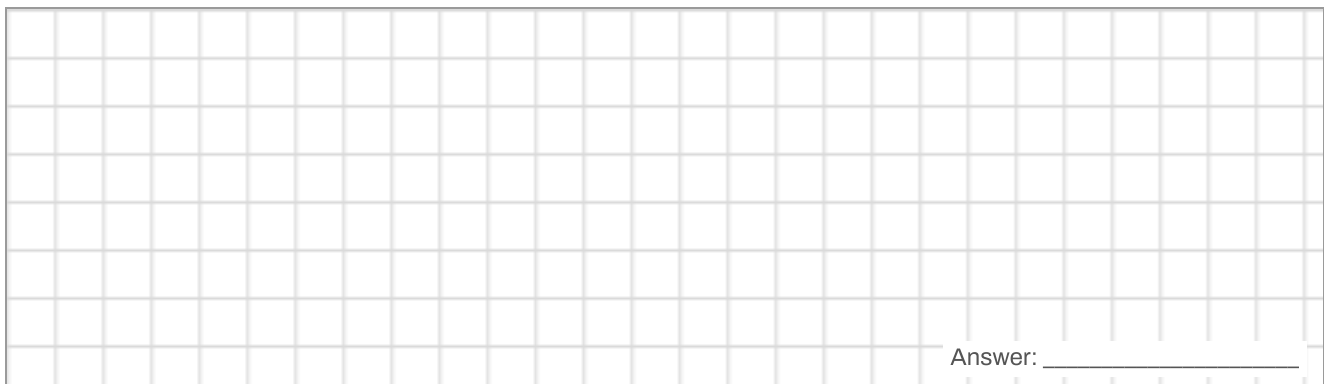
Answer: _____

- 2** **★ ROOKIE** The table jumps from 26 ft to 33 ft. Estimate the speed for a 30-ft gap from the table, then check it with the formula.



Answer: _____

- 3** **★★ PRO** Clue: the launch ramp rises 5 ft over a 13.7 ft run along the ground. What angle is it?



Answer: _____

- 4** **★★ PRO** The speed ladder goes 25, 30, 35, then 40 mph. What gap goes with each step on the kit? When the speed doubles, what happens to the gap?

Answer: _____

- 5** **★★★ ENGINEER** Engineer: rider and wheel together weigh about 275 lb (125 kg). Holding speed up a ramp face takes $\text{mass} \times g \times \text{speed} \times \sin(\text{angle})$ watts, plus the power to push through the air ($\frac{1}{2} \times 1.2 \times 0.6 \times \text{speed}^3$). Can the wheel hold 40 mph up the 20° face if it can give 8.4 kW and keep its reserve? What's the fastest it can hold? What about a 15° face at 40 mph?

Answer: _____

PREDICT THE STUNT

Before the episode, write your prediction. On the night, fill in the real number. How close = $(\text{your number} - \text{real number}) \div \text{real number} \times 100$.

What gets measured	My prediction	The real number	How close (%)
Speed at the lip, every run			
Where the wheel touches down			
Motor power on the ramp face			

THE ENGINEER'S QUESTION

"Same blueprint, same angle, same height, at every venue."

This has to be true before the attempt. Why?

Solve it. Don't try it.

WATCH THE REAL NUMBERS: 9BRT.COM/EPISODES/

Take Style

Does standing side-on really use less energy?

THE STUNT

Before any jump, the stance. Hips open to one side, legs locked, all the weight on a big-toe hook, a tap of the free foot to get moving. It feels like wakeboarding. I say it goes farther on the same battery. Episode 00 is finding out if that's true.

THE IDEA

How far a wheel goes is the battery's energy divided by the energy it uses per mile. A big share of that energy goes into pushing air out of the way, and the push grows with the area you present to the wind.

THE PHYSICS

$$\text{Drag force} = \frac{1}{2} \times \text{air density} \times \text{drag coefficient} \times \text{frontal area} \times \text{speed}^2$$

WORDS TO KNOW

Watt-hour (Wh)

A unit of energy. One watt for one hour, or 3,600 joules.

Frontal area

How big you look to the air coming at you.

Fair test

An experiment where only one thing changes, so you know what caused the result.

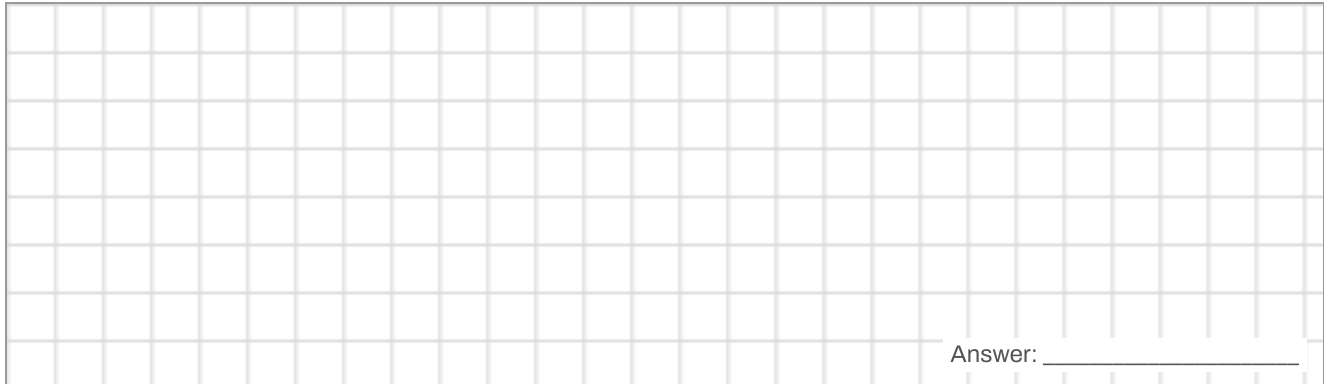
Worked example. A 2,000 Wh battery uses 30 Wh per mile. How far does it go? How far at 27 Wh per mile?

1. Range = battery ÷ energy per mile = $2,000 \div 30 = 66.7$ miles.
2. At 27 Wh per mile: $2,000 \div 27 = 74.1$ miles.
3. Saving 3 Wh per mile adds 7.4 miles.

YOUR TURN

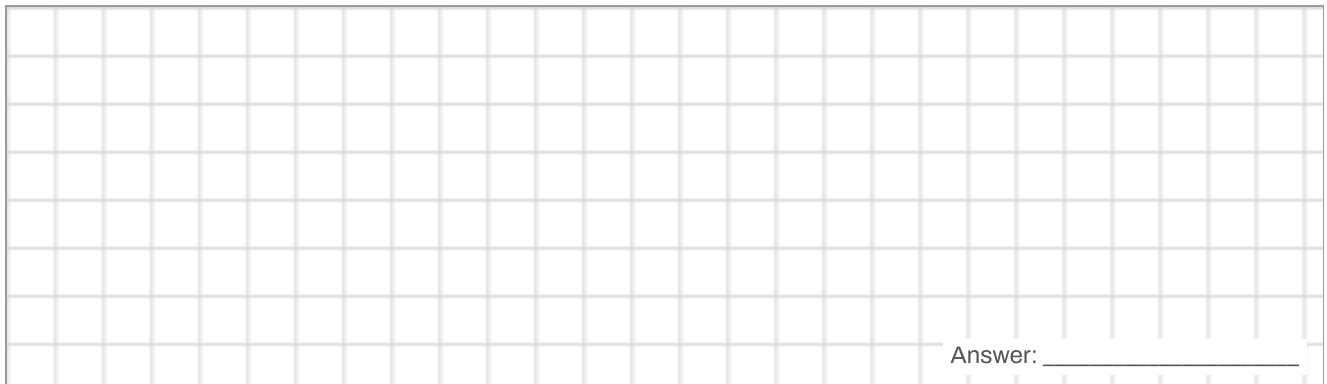
Show your work. Round to the same number of decimal places as the numbers you're given.

- 1** **★ ROOKIE** Using the same 2,000 Wh battery, how many Wh per mile would the wheel have to use to go 10 miles farther than it does at 30 Wh per mile? What percent saving is that?



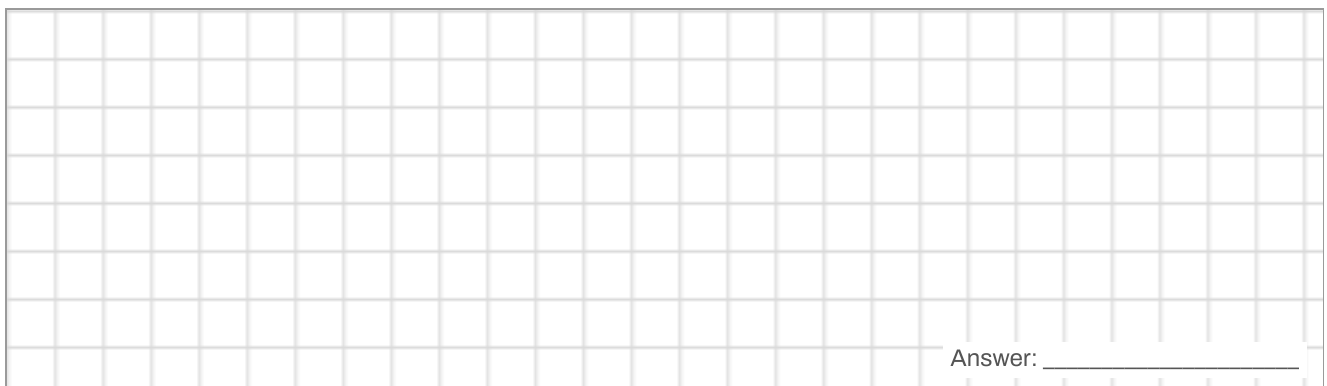
Answer: _____

- 2** **★★ PRO** Find the drag force at 25 mph (11.18 m/s) facing forward and standing side-on. Air density is 1.2 kg/m^3 and the drag coefficient is 1.0. The rider's frontal area is 0.55 m^2 facing forward and 0.40 m^2 side-on.



Answer: _____

- 3** **★★ PRO** The energy to push through the air for one mile is the drag force times the distance (1 mile = 1,609 m). Find it for both stances in Wh (divide joules by 3,600). How much does side-on save per mile, and is that enough for problem 1?



Answer: _____

4

★ ROOKIE

List five things that must stay the same in both runs for the test to be fair.

PREDICT THE STUNT

Before the episode, write your prediction. On the night, fill in the real number. How close = (your number – real number) ÷ real number × 100.

What gets measured	My prediction	The real number	How close (%)
Watt-hours per mile in each stance			
Speed held on the same loop			
Tire pressure, temperature and wind, so the comparison is fair			

THE ENGINEER'S QUESTION

"The result gets published even if the stance loses."

This has to be true before the attempt. Why?

Solve it. Don't try it.

WATCH THE REAL NUMBERS: 9BRT.COM/EPISODES/TAKE-STYLE/

The Empty Bus

When is a bus the cheapest way to move people, and when would a Lamborghini be cheaper?

THE STUNT

A 40-foot city bus parked sideways in a lot, nobody on board. A ramp on one side, a landing on the other, and the wheel goes over the roof. It opens the season, and it comes with a question about the bus itself.

THE IDEA

Two problems. The jump: clearing the roof is a height problem, like the Zamboni. The bus: it costs about the same to run a bus with 2 people on board or 60, so the cost of each ride is the cost of running the bus divided by the riders. How full the bus is changes everything.

THE PHYSICS

Cost per rider per mile = cost to run the vehicle one mile ÷ riders on board

WORDS TO KNOW

Cost per rider-mile

What it costs to carry one person one mile: vehicle cost per mile ÷ riders on board.

Load

How many people are on board on average.

Peak demand

The busiest time, like rush hour, that the system has to be sized for.

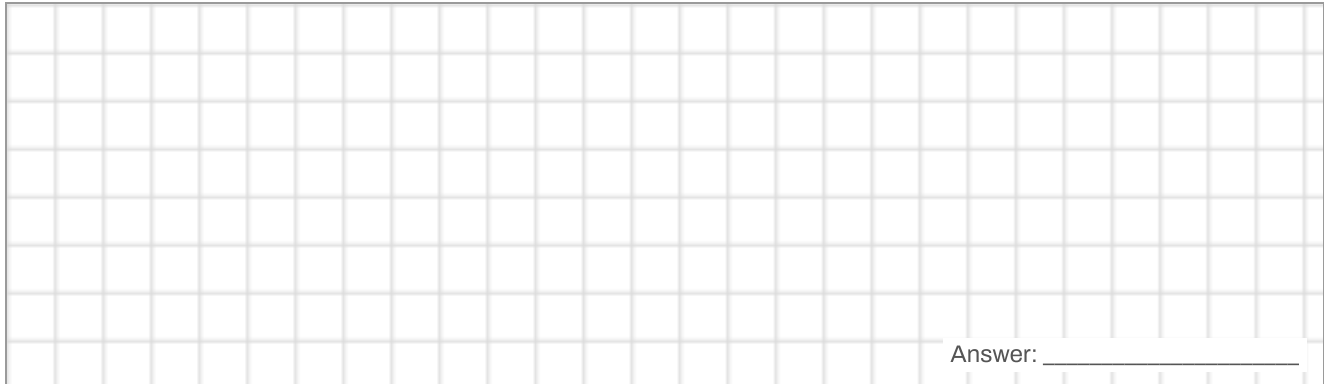
Worked example. In 2024 it cost Metro St. Louis \$13.44 to run a bus one mile, with 6.4 riders on board on average. What does each rider's mile cost?

1. Riders on board = passenger miles ÷ bus miles = $76,719,531 \div 11,973,112 = 6.41$.
2. Cost per rider-mile = $\$13.44 \div 6.41 = \2.10 .
3. Fares paid for about 8 cents of every dollar it cost to run the buses.

YOUR TURN

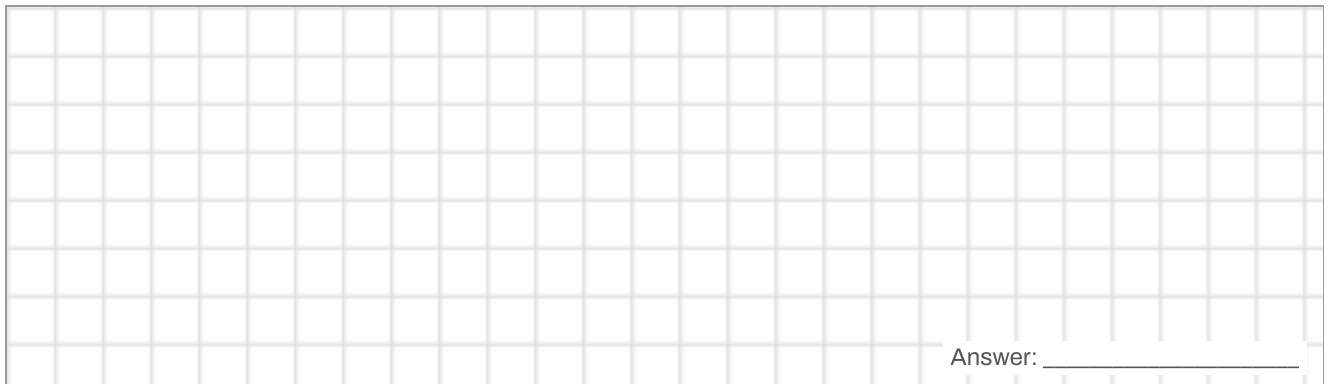
Show your work. Round to the same number of decimal places as the numbers you're given.

- 1** **★★ PRO** The jump. The bus is about 3.2 m (10.5 ft) tall. The season's 20° ramp kit sits on 3.0 m (10 ft) towers, and the wheel should clear the roof by 0.5 m at the top of the arc. What speed does it take at the lip?



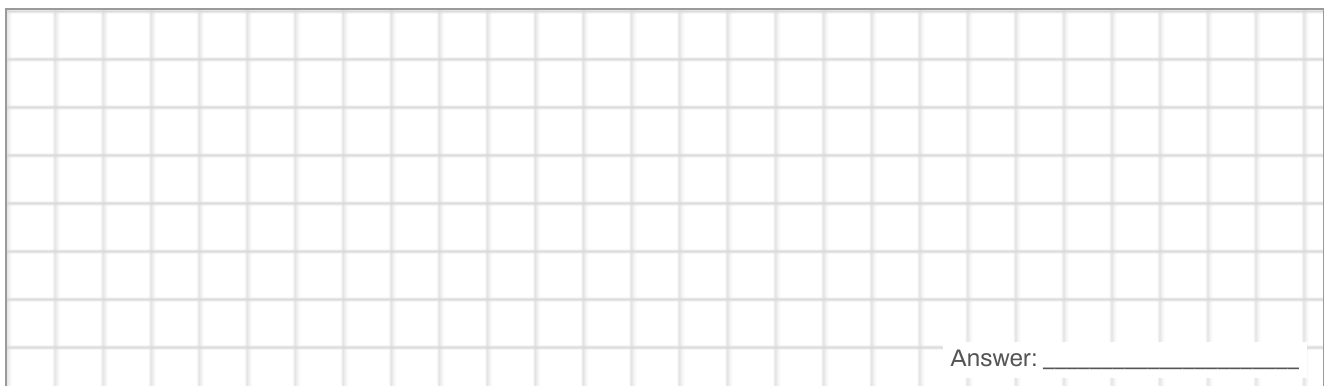
Answer: _____

- 2** **★★★ ENGINEER** With identical ramps at the same height, the top of the arc is exactly halfway across. At the speed from problem 1, how wide is the gap between the lips? The bus is 2.6 m wide and parked in the middle. How much room is there over the roof's edges?



Answer: _____

- 3** **★ ROOKIE** The bus. Using \$13.44 a mile, how many riders does a bus need for each rider's mile to cost under 50 cents? Under \$1?



Answer: _____

- 4** **★★ PRO** Now the Lamborghini. Suppose a chauffeured Urus works like this: it costs \$281,000, is driven 45,000 miles a year for 5 years, then sells for \$50,000. It gets 20 mpg with gas at \$3.20. Insurance is \$12,000 a year. Repairs and tires are 50 cents a mile. The driver costs \$40 an hour, and city traffic averages 14 mph. What does it cost per mile? Per rider-mile with 4 riders?

Answer: _____

- 5** **★★ PRO** How many riders does the bus need before each one rides for less than in the full SUV? Then rush hour: 60 people at one stop. What does it cost per mile to move them in SUVs, 4 to a car, compared with one bus?

Answer: _____

- 6** **★ ROOKIE** So why do cities run big buses all day? Give two reasons. Then name one thing a city could do when a route runs nearly empty.

PREDICT THE STUNT

Before the episode, write your prediction. On the night, fill in the real number. How close = (your number – real number) ÷ real number × 100.

What gets measured	My prediction	The real number	How close (%)
Speed at the lip			
Clearance over the roof			
Landing force in g			

THE ENGINEER'S QUESTION
"Landed over a bus-sized frame at ground level first."
This has to be true before the attempt. Why?

Solve it. Don't try it.

WATCH THE REAL NUMBERS: 9BRT.COM/EPISODES/THE-EMPTY-BUS/

79 in One

What's the shortest route that touches all 79, and does the battery make it?

THE STUNT

St. Louis has 79 neighborhoods. Most people have been to a dozen. I'm riding into every one of them between sunrise and midnight, with a checkpoint and a photo in each.

THE IDEA

Visiting many places by the shortest route is one of the most famous problems in math: the traveling salesperson problem. Then comes an energy budget. The miles times the energy per mile has to fit in the battery, or you plan the charging stops.

THE PHYSICS

Energy needed = route miles × watt-hours per mile

WORDS TO KNOW

Traveling salesperson problem

Finding the shortest loop that visits every point once.

Energy budget

Adding up the energy a trip needs before you start.

Reserve

Energy you plan never to use, in case something goes wrong.

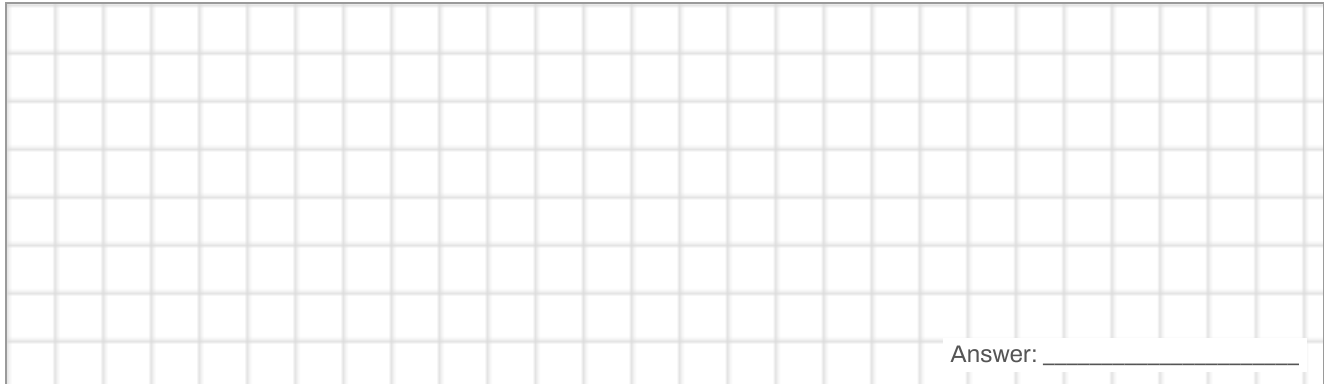
Worked example. A 2,000 Wh battery at 30 Wh per mile. How far per charge? How far if you always keep 20% in reserve?

1. Full battery: $2,000 \div 30 = 66.7$ miles.
2. Keeping 20% in reserve leaves 80% of 2,000 = 1,600 Wh to use.
3. $1,600 \div 30 = 53.3$ miles per charge.

YOUR TURN

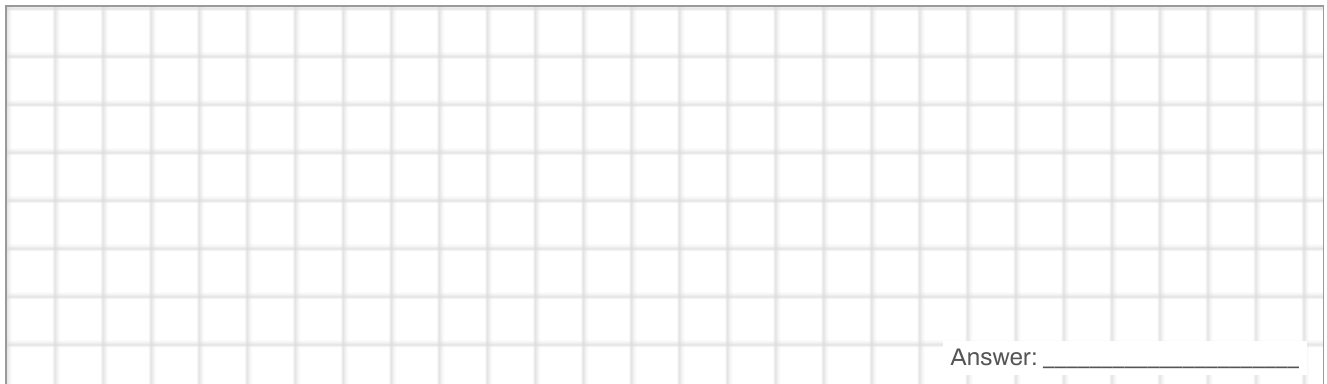
Show your work. Round to the same number of decimal places as the numbers you're given.

- 1** **★ ROOKIE** Five checkpoints, A to E, are this many miles apart: A–B 4, A–C 7, A–D 6, A–E 3, B–C 3, B–D 8, B–E 5, C–D 4, C–E 6, D–E 5. Start and finish at A and visit each checkpoint once. There are 12 different loops. Find the shortest.



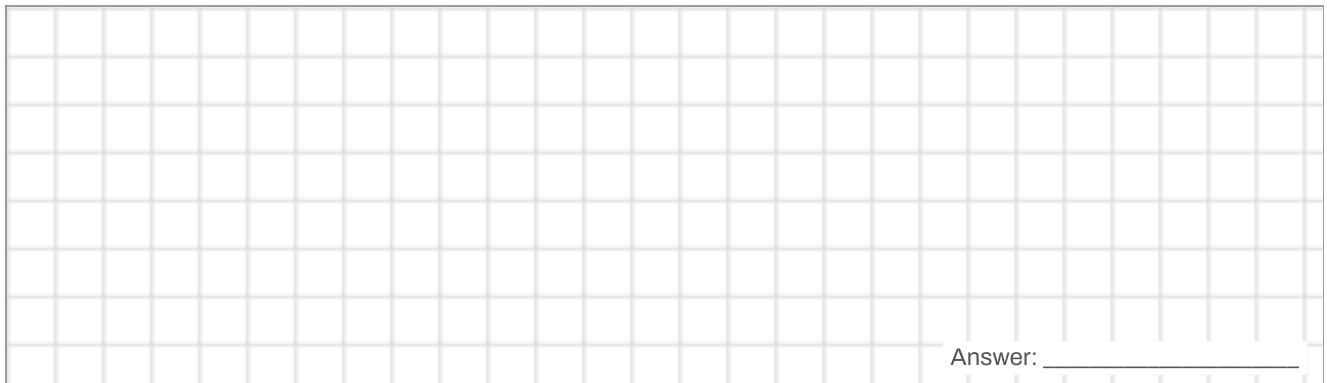
Answer: _____

- 2** **★ ROOKIE** Suppose the full 79-neighborhood route is 120 miles at 30 Wh per mile. How much energy does it need? Keeping a 20% reserve (1,600 Wh usable per charge) and starting full, how many charging stops does it take?



Answer: _____

- 3** **★★ PRO** Sunrise to midnight is 17 hours. The wheel averages 14 mph while moving. Each of the 79 checkpoints takes 3 minutes for its photo. Each charging stop puts back 1,600 Wh from an 800-watt charger. Does the day fit, and how much time is left over?



Answer: _____

PREDICT THE STUNT

Before the episode, write your prediction. On the night, fill in the real number. How close = (your number – real number) ÷ real number × 100.

What gets measured	My prediction	The real number	How close (%)
The GPS track, proving all 79			
Total miles, ride time and stopped time			
Energy used and every charge stop			

THE ENGINEER'S QUESTION
"Daylight for the worst pavement."

This has to be true before the attempt. Why?

Solve it. Don't try it.

WATCH THE REAL NUMBERS: 9BRT.COM/EPISODES/79-IN-ONE/

The Keg Line

How fast at the lip to clear ten kegs?

THE STUNT

Two ramps and a row of kegs between them. Clear it clean and one more keg goes in. It's the New Year's party, and the count is the whole show.

THE IDEA

Between two ramps of the same height, the wheel is a projectile. How far it flies depends only on its speed at the lip and the ramp's angle. Distance grows with the square of speed, so a little speed buys a lot of distance.

THE PHYSICS

$$\text{Distance} = \text{speed}^2 \times \sin(2 \times \text{ramp angle}) \div g$$

WORDS TO KNOW

Projectile

Anything flying with only gravity acting on it.

Takeoff angle

The angle of the ramp's lip above horizontal.

Range

The horizontal distance from takeoff to landing.

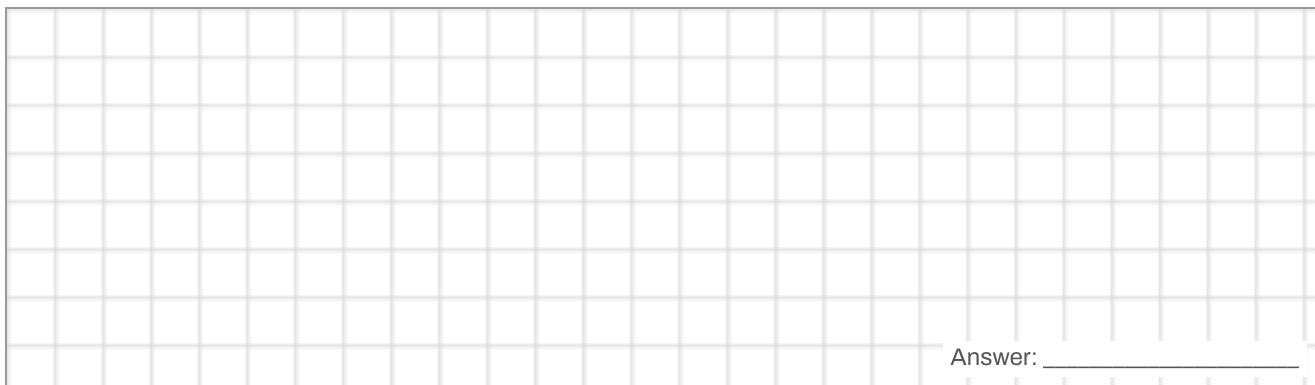
Worked example. Ten kegs, each about 16 inches wide, between two 20° ramps. How fast at the lip?

1. Distance = $10 \times 16 \text{ in} = 160 \text{ in} = 4.06 \text{ m}$.
2. Rearrange: $\text{speed} = \sqrt{(\text{distance} \times g \div \sin(2 \times \text{angle}))}$.
3. $\sin(40^\circ) = 0.643$. Speed = $\sqrt{(4.06 \times 9.8 \div 0.643)} = 7.87 \text{ m/s}$.
4. $7.87 \text{ m/s} \div 0.447 = 17.6 \text{ mph}$.

YOUR TURN

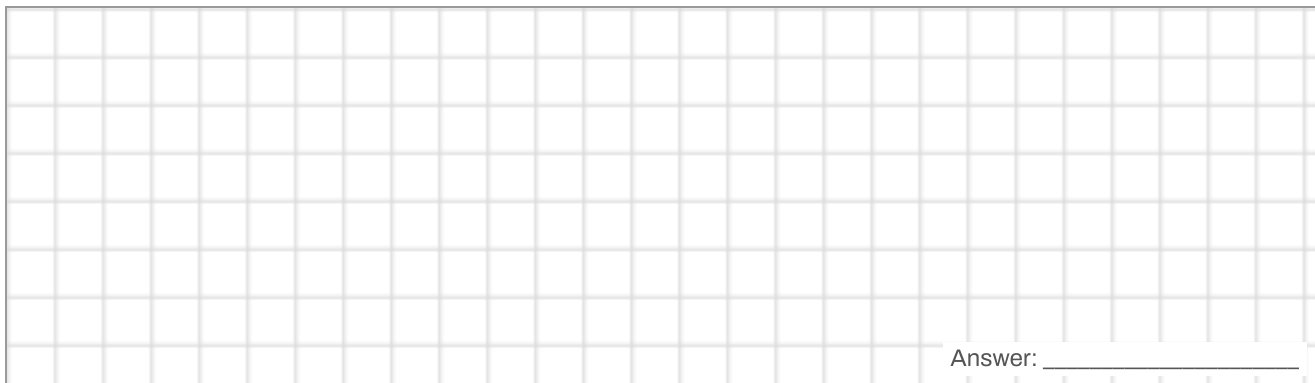
Show your work. Round to the same number of decimal places as the numbers you're given.

- 1** **★★ PRO** Twelve kegs off the same 20° ramps. What speed at the lip?



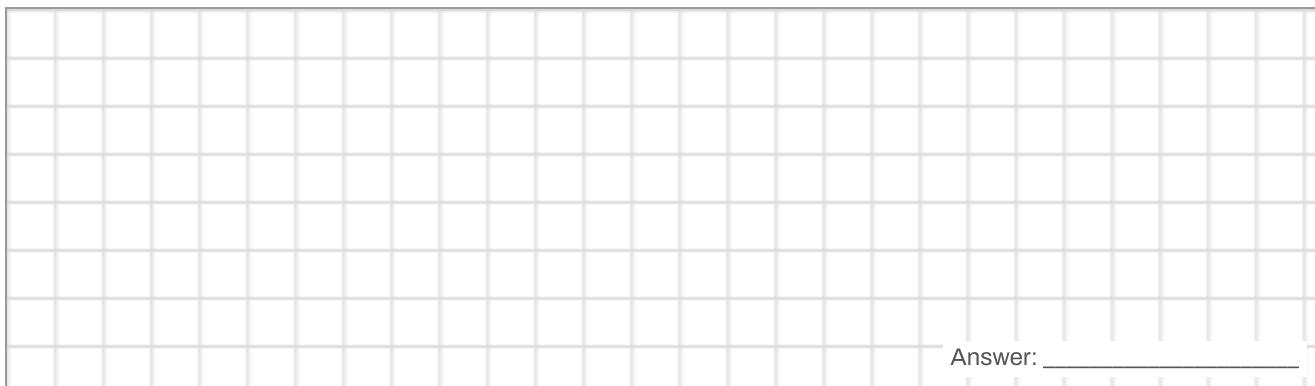
Answer: _____

- 2** **★★ PRO** Ten kegs again, but with 30° ramps. What speed now? Give one reason the rider might still choose 20° .



Answer: _____

- 3** **★★ PRO** How long is the wheel in the air in the worked example? $\text{Time in the air} = 2 \times \text{speed} \times \sin(\text{angle}) \div g$.



Answer: _____

- 4** **★★★ ENGINEER** The rider arrives 1 mph slow on the ten-keg jump at 20°. How far does the wheel go, and how short does it land?

Answer: _____

PREDICT THE STUNT

Before the episode, write your prediction. On the night, fill in the real number. How close = (your number – real number) ÷ real number × 100.

What gets measured	My prediction	The real number	How close (%)
Speed at the lip			
Time in the air and distance cleared			
Landing force in g			

THE ENGINEER'S QUESTION

"The count only goes up after a clean landing."

This has to be true before the attempt. Why?

Solve it. Don't try it.

WATCH THE REAL NUMBERS: 9BRT.COM/EPISODES/KEG-LINE/

Jump the Zamboni

How high does the jump have to go, and can a tire grip ice hard enough to get there?

THE STUNT

January, an outdoor rink, and the ice-resurfacing machine parked at center ice. The wheel gets a studded tire. Then it goes over the machine.

THE IDEA

Two problems at once. How high the arc goes depends on the upward part of the speed at the lip. Getting to that speed depends on grip, and ice gives a rubber tire almost nothing to push against, which is why the tire gets studs.

THE PHYSICS

$$\text{Peak height above the lip} = (\text{speed} \times \sin(\text{ramp angle}))^2 \div (2 \times g)$$

WORDS TO KNOW

Vertical component

The part of the speed pointing straight up: $\text{speed} \times \sin(\text{angle})$.

Coefficient of friction

How hard a surface lets you push sideways compared with your weight.

Run-up

The distance used to get up to speed before the lip.

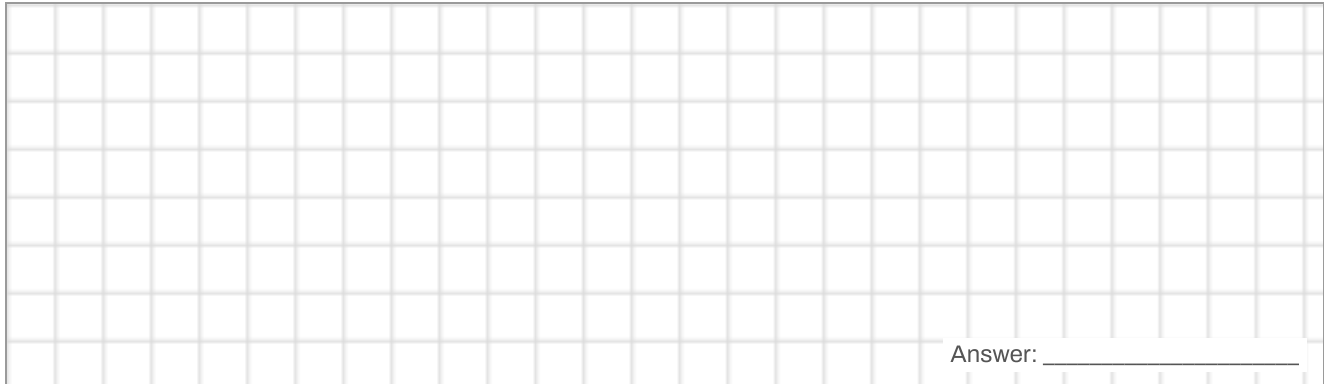
Worked example. On the season's 20° ramp kit, how high above the lip does the arc peak at 20 mph?

1. 20 mph = 8.94 m/s. Upward part = $8.94 \times \sin(20^\circ) = 3.06$ m/s.
2. Peak height = $3.06^2 \div (2 \times 9.8) = 0.48$ m, about 1.6 feet.

YOUR TURN

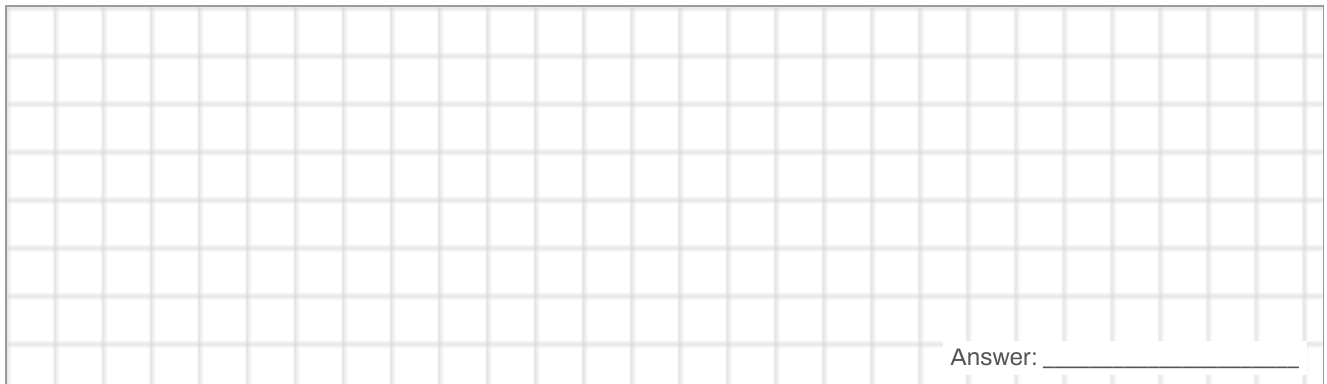
Show your work. Round to the same number of decimal places as the numbers you're given.

- 1** **★★ PRO** Suppose the machine is 2.0 m tall and the kit's lips are 1.5 m (5 ft) off the ice. The wheel should clear the machine by 0.3 m at the top of the arc. How high above the lip must the arc peak, and what speed does that take at the lip?



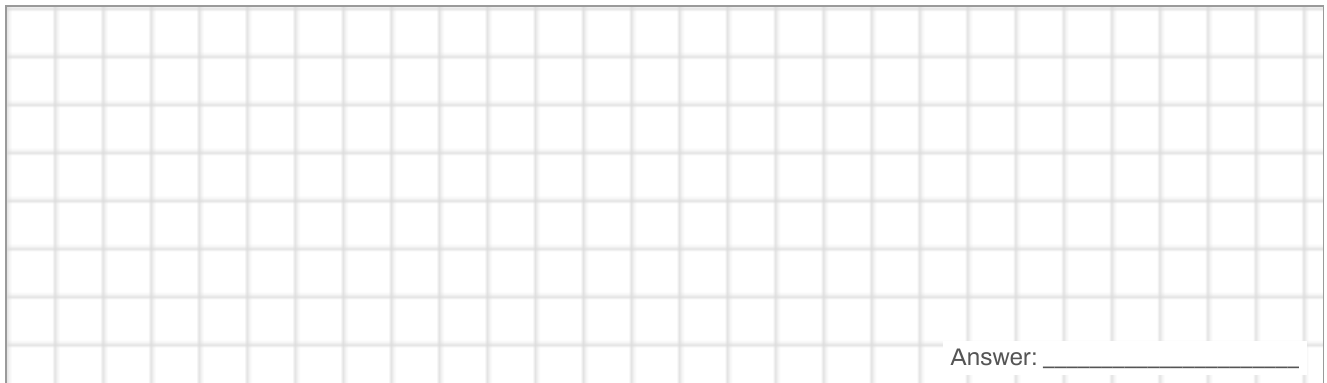
Answer: _____

- 2** **★★★ ENGINEER** The quickest a tire can speed you up is about (friction coefficient $\times$ g). Say plain rubber on ice is 0.1 and a studded tire is 0.3. The run-up needed = $\text{speed}^2 \div (2 \times \text{acceleration})$. The machine sits at center ice, about 30 m from the end boards. Which tire can reach the speed from problem 1 in time?



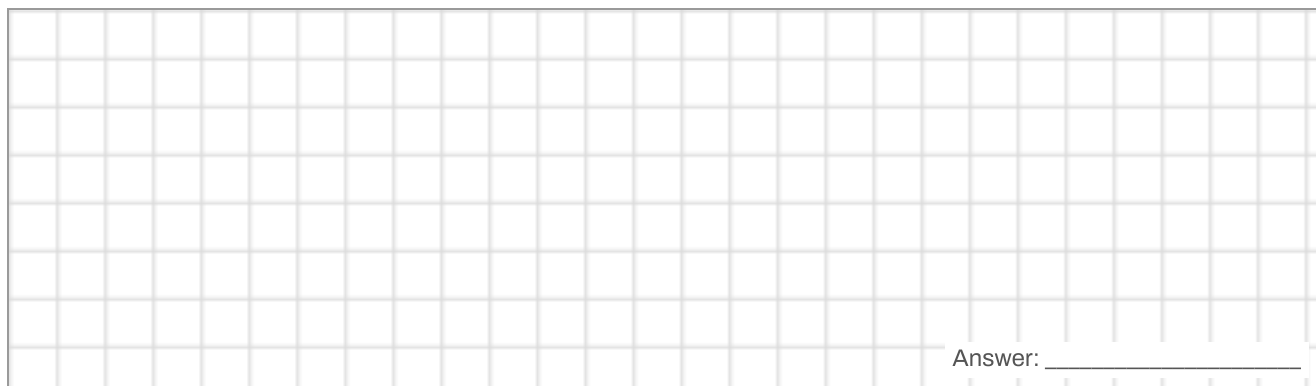
Answer: _____

- 3** **★★★ ENGINEER** The rider arrives 1 mph slow. Does the wheel still clear the machine, and by how much?



Answer: _____

- 4 ★★ PRO** Where does the machine go? With identical ramps the top of the arc is halfway across. At the speed from problem 1, how wide is the gap between the lips, and how far from the launch lip is the top of the arc?



PREDICT THE STUNT

Before the episode, write your prediction. On the night, fill in the real number. How close = (your number – real number) ÷ real number × 100.

What gets measured	My prediction	The real number	How close (%)
Speed and wheel slip on the run-up			
Peak height over the machine			
Landing force on ice			

THE ENGINEER'S QUESTION

"The studded tire is tested for grip before any ramp goes down."

This has to be true before the attempt. Why?

Solve it. Don't try it.

WATCH THE REAL NUMBERS: 9BRT.COM/EPISODES/JUMP-THE-ZAMBONI/

The Parade

Why is it harder to balance slow than fast?

THE STUNT

Mardi Gras weekend in Soulard, one of the biggest crowds St. Louis puts on a street all year, and a stunt in the middle of it. The stunt gets chosen with the hosts and sized to the street.

THE IDEA

A rider on a wheel is an inverted pendulum, like a broomstick balanced on your palm. It starts to fall the moment it's upright, and the taller it is, the slower it falls. The wheel's motor catches the front-to-back fall over and over, many times a second. Side to side, the rider steers under the fall.

THE PHYSICS

A feedback loop: sense the lean, correct, repeat

WORDS TO KNOW

Inverted pendulum

A weight balanced above its pivot. It falls unless something keeps correcting it.

Feedback loop

Sense, correct, sense again. The faster the loop, the smaller each correction.

Fall time

Roughly $\sqrt{(\text{height of the balance point} \div g)}$. Taller things fall more slowly.

Worked example. Why is a broomstick easier to balance than a pencil?

1. Broomstick, balance point about 1.5 m up: $\sqrt{(1.5 \div 9.8)} = 0.39$ s.
2. Pencil, about 0.15 m: $\sqrt{(0.15 \div 9.8)} = 0.12$ s.
3. The pencil falls about 3.2 times faster, faster than a hand can react.

YOUR TURN

Show your work. Round to the same number of decimal places as the numbers you're given.

- 1 ★ ROOKIE** A rider's balance point is about 1.0 m above where the tire touches the ground. What's the fall time? If the wheel's controller corrects 1,000 times a second, how many corrections fit inside it?

Answer: _____

- 2 ★★ PRO** Side to side, the rider stays up by steering. The sideways push a turn gives you is $\text{speed}^2 \div \text{turn radius}$. Compare 3 mph and 12 mph through the same 3 m turn.

[illegible]

- 3 ★ ROOKIE** Experiment: balance a broomstick on your palm, then a 30 cm ruler, five tries each, and time each try. Average them. Which lasted longer, and by about how much does the fall-time formula say it should?

PREDICT THE STUNT

Before the episode, write your prediction. On the night, fill in the real number. How close = (your number – real number) ÷ real number × 100.

What gets measured	My prediction	The real number	How close (%)
Slowest speed held without a foot down			
Corrections per second from the wheel's own sensors			
Crowd noise in decibels at the stunt			

THE ENGINEER'S QUESTION
"No kids inside the stunt zone."

This has to be true before the attempt. Why?

Solve it. Don't try it.

WATCH THE REAL NUMBERS: 9BRT.COM/EPISODES/THE-PARADE/

The Bend

How far do you have to lean to hold a turn at speed?

THE STUNT

An old steel bridge, a mile of it, closed to cars for decades, with a 22-degree bend in the middle of the river. One run, at night, lit end to end, timed through the bend.

THE IDEA

In a turn, the tire has to push you toward the inside, and you lean so that push and gravity line up through you. Faster or tighter means more lean, until the tire runs out of grip.

THE PHYSICS

$$\tan(\text{lean angle}) = \text{speed}^2 \div (\text{turn radius} \times g)$$

WORDS TO KNOW

Lean angle

How far the wheel and rider tip from vertical in a turn.

Turn radius

The radius of the circle the turn is part of.

Grip limit

The most sideways push the tire can give before it slides.

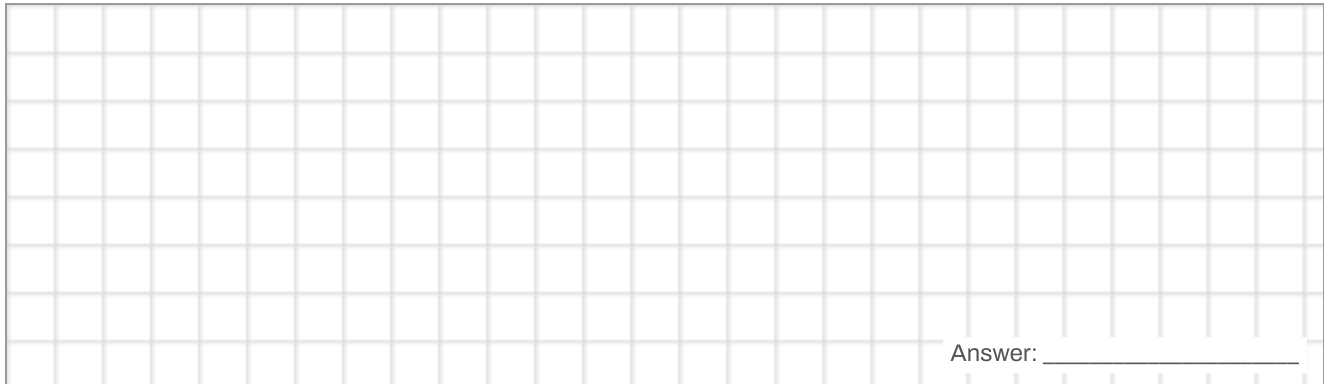
Worked example. 30 mph around a 50 m radius. How far does the rider lean?

1. 30 mph = 13.41 m/s. $\text{speed}^2 = 179.9$.
2. $\tan(\text{lean}) = 179.9 \div (50 \times 9.8) = 0.367$.
3. Lean = 20.2° .

YOUR TURN

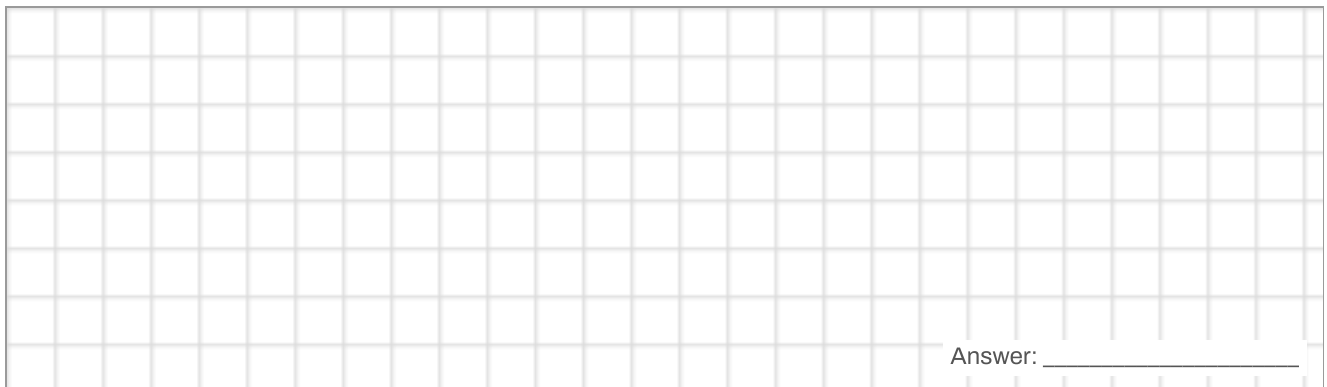
Show your work. Round to the same number of decimal places as the numbers you're given.

- 1** **★★ PRO** The same 50 m turn at 20 mph. What's the lean?



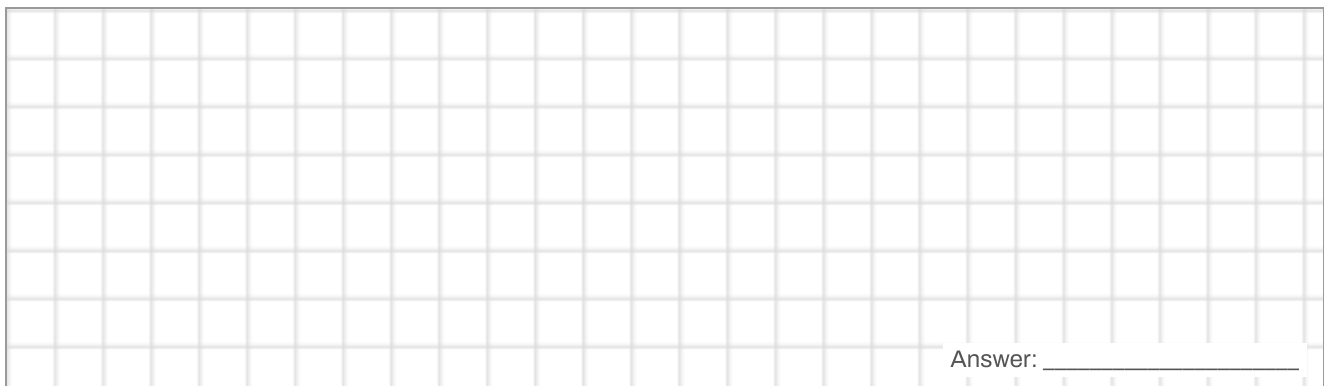
Answer: _____

- 2** **★★★ ENGINEER** A tire slides when $\tan(\text{lean})$ would have to be more than the friction coefficient. With 0.8 on dry pavement, what's the most lean, and the fastest speed around the 50 m turn? With 0.5 on a damp deck?



Answer: _____

- 3** **★★★ ENGINEER** Suppose a map shows the bridge's bend turning 22° across 120 m of deck. Radius = arc length $\div$ angle in radians. Find the radius, then the lean at 30 mph. Is the bend the hard part?



Answer: _____

PREDICT THE STUNT

Before the episode, write your prediction. On the night, fill in the real number. How close = (your number – real number) ÷ real number × 100.

What gets measured	My prediction	The real number	How close (%)
Speed entering, in and leaving the bend			
Lean angle from the wheel's sensors			
Time over the full mile			

THE ENGINEER'S QUESTION

"The deck inspected seam by seam."

This has to be true before the attempt. Why?

Solve it. Don't try it.

WATCH THE REAL NUMBERS: 9BRT.COM/EPISODES/THE-BEND/

The Spirit

Why does going twice as fast take eight times the power?

THE STUNT

A closed runway, a timing trap, and as fast as the wheel will safely go. Two passes in opposite directions, averaged, so the wind can't help.

THE IDEA

Air drag grows with the square of speed, and power is force times speed, so the power to beat the air grows with the cube. Twice the speed takes eight times the power. A one-wheel has a second problem: the motor that moves you also balances you, so it can never run out.

THE PHYSICS

$$\text{Power to beat drag} = \frac{1}{2} \times \text{air density} \times \text{drag coefficient} \times \text{frontal area} \times \text{speed}^3$$

WORDS TO KNOW

Power

How fast energy is used, in watts.

Drag area

Drag coefficient $\times$ frontal area, in m^2 .
Smaller is slipperier.

Reserve

Power held back on purpose so the wheel can still balance.

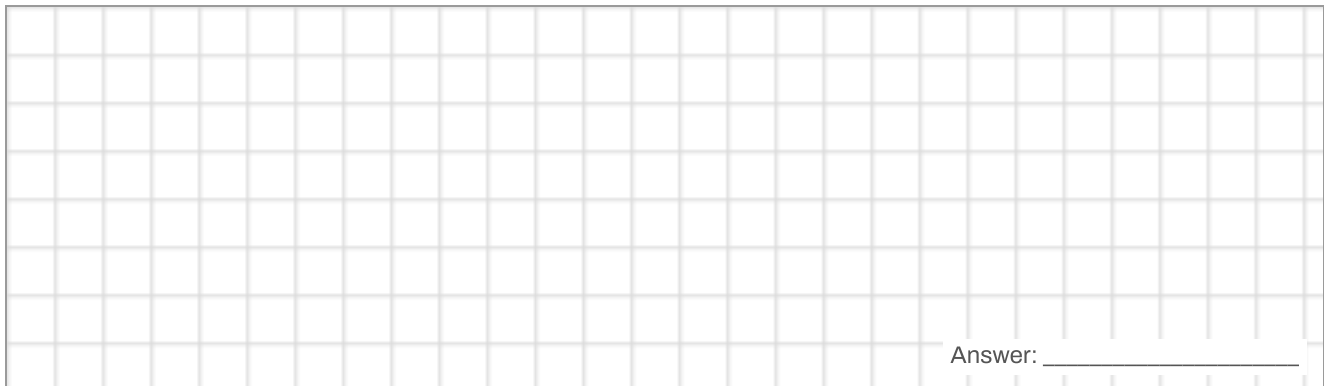
Worked example. With a drag area of 0.6 m^2 , how much power does it take to beat the air at 25 mph?
At 50 mph?

1. 25 mph = 11.18 m/s. Power = $\frac{1}{2} \times 1.2 \times 0.6 \times 11.18^3 = 503 \text{ W}$.
2. 50 mph = 22.35 m/s. Power = $\frac{1}{2} \times 1.2 \times 0.6 \times 22.35^3 = 4,020 \text{ W}$.
3. Twice the speed, 8 times the power.

YOUR TURN

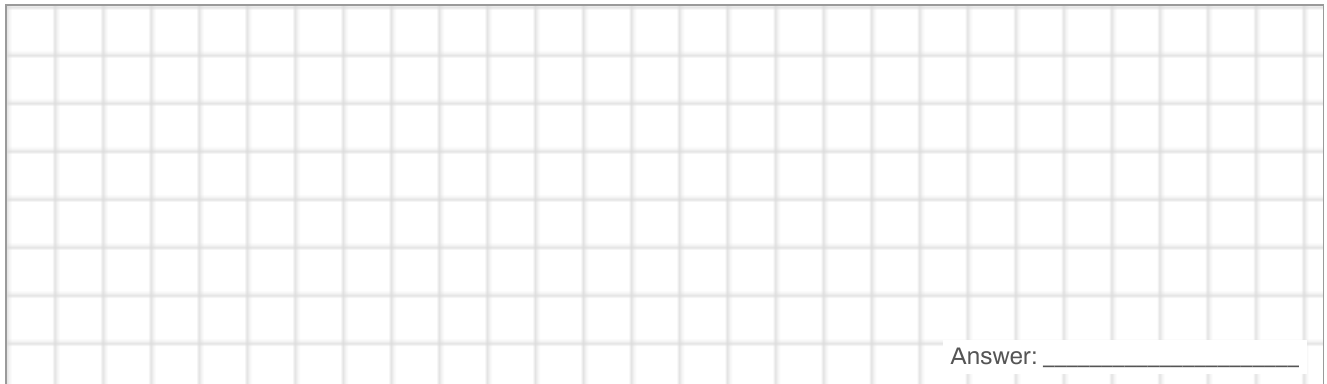
Show your work. Round to the same number of decimal places as the numbers you're given.

- 1** **★★ PRO** How much power does it take at 40 mph?



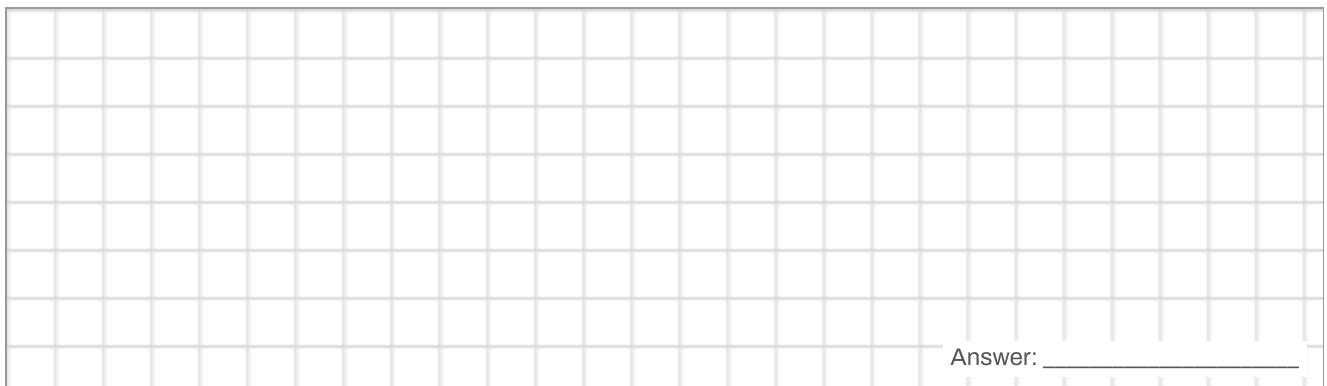
Answer: _____

- 2** **★★★ ENGINEER** The motor can put 3,000 W into fighting the air, but 30% has to stay in reserve for balance. What's the top speed?



Answer: _____

- 3** **★★★ ENGINEER** Tucking cuts the drag area to 0.45 m^2 . With the same usable power, what's the new top speed? What drag area would it take to gain a full 5 mph over problem 2?



Answer: _____

4

★ ROOKIE

With the wind behind him the timing trap reads 44 mph. Against the wind it reads 38 mph. What speed goes in the record, and why run both directions?

Answer: _____

PREDICT THE STUNT

Before the episode, write your prediction. On the night, fill in the real number. How close = (your number – real number) ÷ real number × 100.

What gets measured	My prediction	The real number	How close (%)
Speed through a timed trap, both directions, averaged			
Motor power and how much reserve was left			
Wind speed and direction			

THE ENGINEER'S QUESTION

"A hard cap on speed that keeps motor power in reserve."

This has to be true before the attempt. Why?

Solve it. Don't try it.

WATCH THE REAL NUMBERS: 9BRT.COM/EPISODES/THE-SPIRIT/

Art Hill

Why do big jumps land on a down-ramp?

THE STUNT

The best natural grandstand in the city is a hill in Forest Park. The crowd sits on the grass. The ramps are at the bottom. This is also where the Solve the Jump finals happen, so the students who did the math watch it get tested.

THE IDEA

Falling builds downward speed. Land on flat ground and the legs have to stop all of it at once. Land on a down-ramp that matches the flight path and the ground only has to stop the small part of the speed pointed into the ramp. That's why every big jump lands on a slope.

THE PHYSICS

Downward speed at landing = $\sqrt{2 \times g \times \text{height fallen}}$

WORDS TO KNOW

Downward speed

How fast you're falling at the moment you land.

Landing angle

The angle of your path below horizontal as you land.

g-force

Acceleration measured in multiples of gravity. 1 g is standing still.

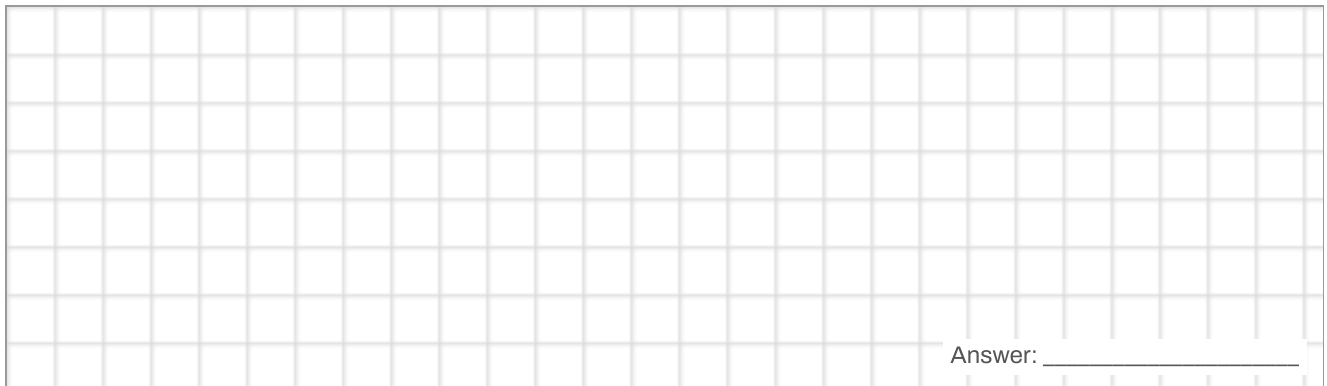
Worked example. The wheel falls 1.5 m. How fast is it moving downward when it lands?

1. Downward speed = $\sqrt{2 \times 9.8 \times 1.5} = \sqrt{29.4} = 5.42 \text{ m/s}$.
2. $5.42 \div 0.447 = 12.1 \text{ mph}$ straight down.

YOUR TURN

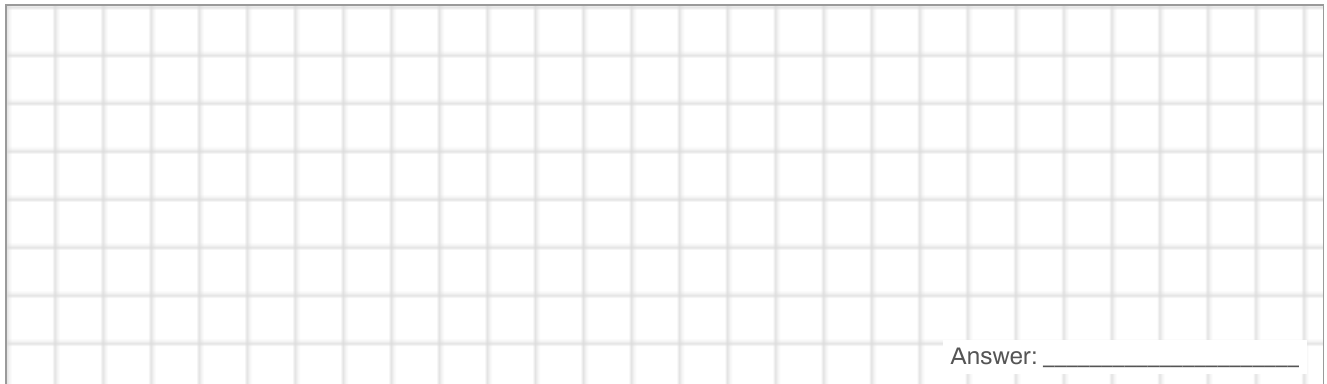
Show your work. Round to the same number of decimal places as the numbers you're given.

- 1** **★★ PRO** What if the drop is 3.0 m? How much faster is that than 1.5 m?



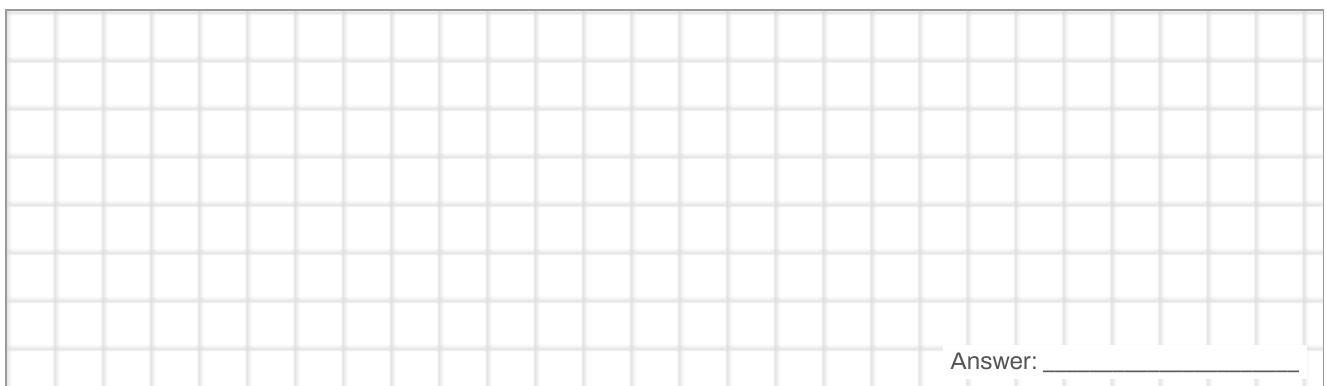
Answer: _____

- 2** **★★ PRO** The wheel is moving forward at 8.0 m/s and falls 1.5 m. At what angle below horizontal is it moving when it lands?



Answer: _____

- 3** **★★★ ENGINEER** Land on a 30° down-ramp instead of flat ground. Only the speed into the ramp has to be stopped: $(\text{downward} \times \cos 30^\circ) - (\text{forward} \times \sin 30^\circ)$. Find it. What share of the flat-ground hit is left?



Answer: _____

★★★ **ENGINEER**

Answer: _____

PREDICT THE STUNT

Before the episode, write your prediction. On the night, fill in the real number. How close = $(\text{your number} - \text{real number}) \div \text{real number} \times 100$.

What gets measured	My prediction	The real number	How close (%)
Takeoff speed and angle			
Distance and height			
Landing force, compared with each team's prediction			

THE ENGINEER'S QUESTION

"Crowd lines set well back from the landing."

This has to be true before the attempt. Why?

Solve it. Don't try it.

WATCH THE REAL NUMBERS: 9BRT.COM/EPISODES/ART-HILL/

Center Stage

If you throw a ball while you're riding, how fast is it really going?

THE STUNT

An open plaza by the ballpark on a game night, a stage at one end and a long runway in front of it. The ramp kit goes on the runway with the gap in front of the stage. On the way in, the first pitch gets thrown from the wheel at speed. Then the jump, the biggest of the season before the finale.

THE IDEA

Speeds add when one moving thing is carried by another. A ball thrown from a moving wheel leaves with the wheel's speed plus the throw; thrown backward, they subtract. The jump uses the ramp kit: the speed at the lip sets how far the wheel flies, and the runway has to be long enough to get up to that speed and to stop afterward.

THE PHYSICS

Ball speed over the ground = wheel speed + throw speed (thrown backward: wheel speed – throw speed)

WORDS TO KNOW

Relative motion

How fast something moves depends on who's measuring: the rider, or the crowd standing still.

Frame of reference

The point of view you measure speed from.

Braking distance

How far it takes to stop: $\text{speed}^2 \div (2 \times \text{braking acceleration})$.

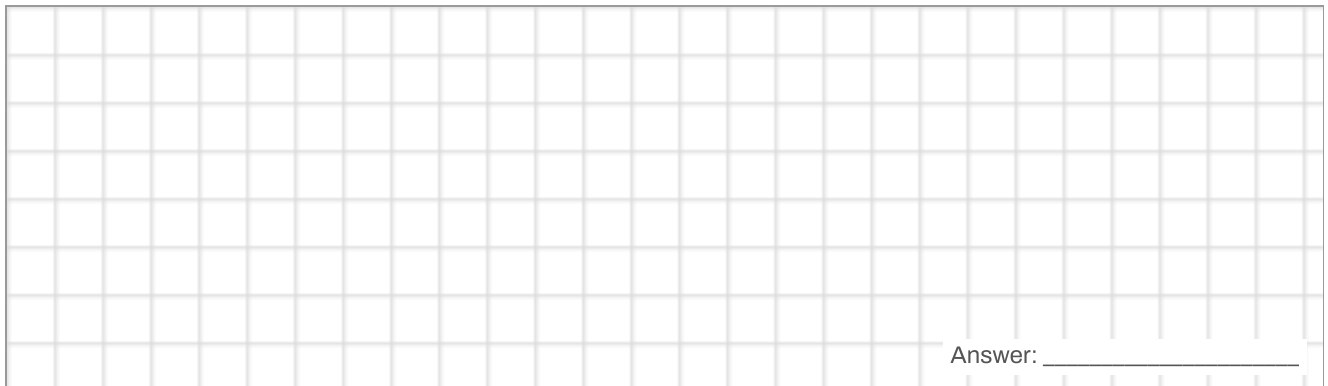
Worked example. Riding at 20 mph, he throws the first pitch forward at 50 mph. How fast does the ball cross the plaza? How fast does it look to him?

1. To the crowd: the wheel's speed and the throw add. $20 + 50 = 70$ mph.
2. To the rider: he's moving with the ball's starting speed, so it leaves him at the 50 mph he threw it.

YOUR TURN

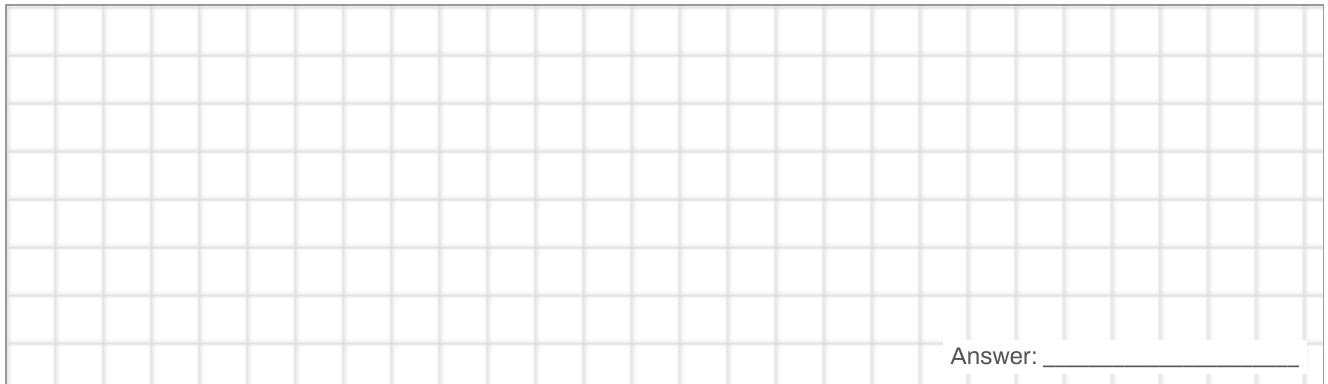
Show your work. Round to the same number of decimal places as the numbers you're given.

- 1** **★ ROOKIE** Riding 15 mph, he throws forward at 45 mph. What's the ball's speed over the ground?



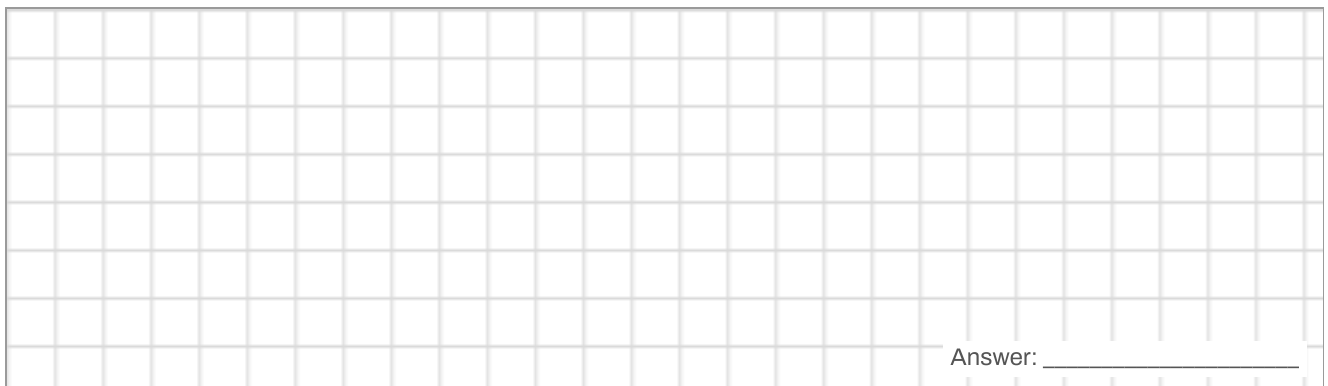
Answer: _____

- 2** **★ ROOKIE** The radar on the plaza reads the pitch at 68 mph. The wheel's GPS says it was doing 21 mph. How hard did he actually throw?



Answer: _____

- 3** **★ ROOKIE** Riding 20 mph forward, he tosses the ball backward at 20 mph. What does the crowd see the ball do? What does the rider see?



Answer: _____

4 **★★ PRO** The jump: 35 mph at the lip on the 20° kit. How wide is the gap, how long is the wheel in the air, and how high above the lip does it go?

Answer: _____

5 **★★★ ENGINEER** The runway. Say the wheel speeds up at 0.3 g and brakes at 0.4 g. How much runway does it take to reach 35 mph? To stop after landing? Add about 15 ft for each ramp and the gap from problem 4. How long does the runway have to be?

Answer: _____

PREDICT THE STUNT

Before the episode, write your prediction. On the night, fill in the real number. How close = (your number – real number) ÷ real number × 100.

What gets measured	My prediction	The real number	How close (%)
Speed at the lip			
Pitch speed by radar, thrown from the wheel			
Landing force in g			

THE ENGINEER'S QUESTION

"Room to stop before the stage."

This has to be true before the attempt. Why?

Solve it. Don't try it.

WATCH THE REAL NUMBERS: 9BRT.COM/EPISODES/CENTER-STAGE/

The Wash Ave Gap

There's no second try. What is the window?

THE STUNT

Two rooftops, nine stories up, a gap between them, and Washington Avenue full of people underneath. One attempt. Everything in the season before this is practice for it.

THE IDEA

There's no second try. Too slow and the wheel lands on the deck before the landing slope; too fast and it overshoots the landing zone. At 40 mph every mile an hour moves the landing about three and a half feet, so the landing zone is the margin, and the math says how long it has to be.

THE PHYSICS

Gap = $\text{speed}^2 \times \sin(2 \times \text{ramp angle}) \div g$, with both lips at the same height

WORDS TO KNOW

Landing zone

The stretch of the landing ramp that's safe to touch down on.

Window

Every speed at the lip that still lands in the zone.

Target speed

The speed the rider aims for: the middle of the window.

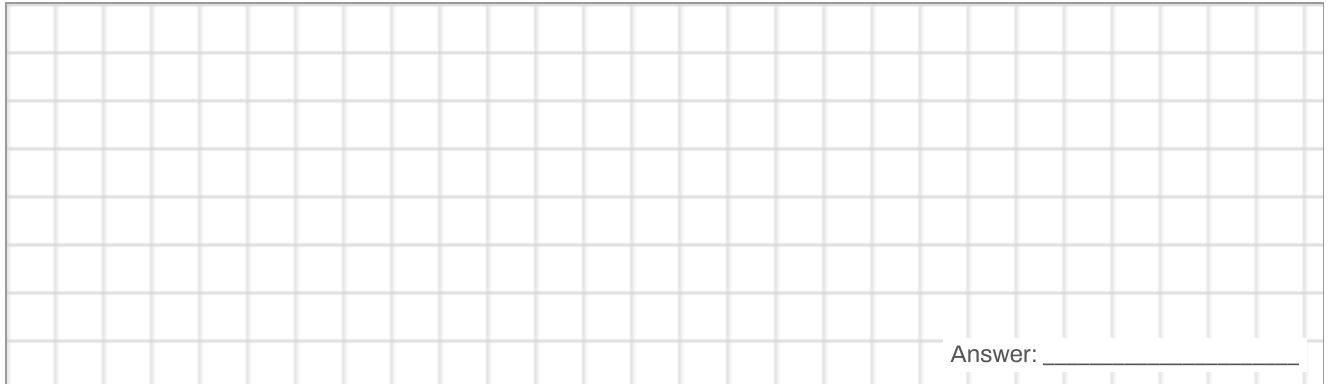
Worked example. On the season's 20° ramp kit, how far does 40 mph at the lip fly, how high, and for how long?

1. 40 mph = 17.88 m/s.
2. Gap = $17.88^2 \times \sin 40^\circ \div 9.8 = 20.97$ m, about 69 ft.
3. Height above the lip = $(17.88 \times \sin 20^\circ)^2 \div 19.6 = 1.91$ m, about 6.3 ft.
4. Air time = $2 \times 17.88 \times \sin 20^\circ \div 9.8 = 1.25$ s.
5. Every 1 mph changes the distance by about 3.4 ft.

YOUR TURN

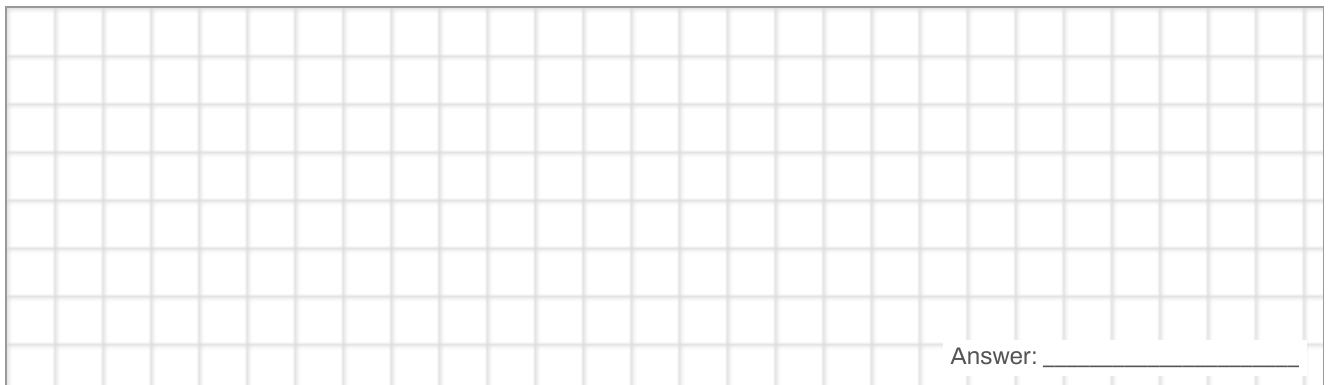
Show your work. Round to the same number of decimal places as the numbers you're given.

- 1** **★ ROOKIE** Every 1 mph moves the landing about 3.4 ft. If the rider hits the lip 3 mph slow, about how far short of 69 ft does he come down? Check it with the gap formula at 37 mph.



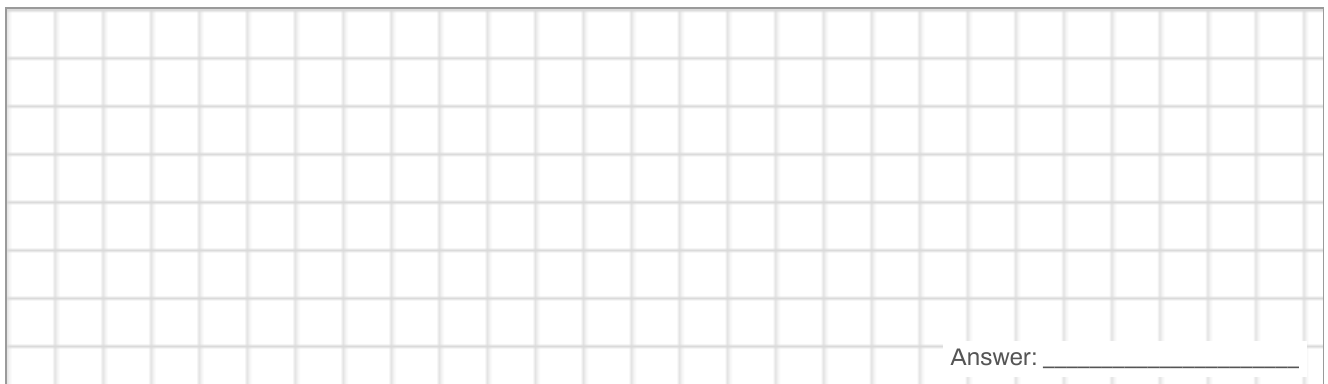
Answer: _____

- 2** **★★ PRO** The safe landing zone runs from 64 ft to 74 ft past the lip. What speed window does that give?



Answer: _____

- 3** **★★★ ENGINEER** How long would the landing zone have to be for a ± 3 mph window around 40 mph?



Answer: _____

★★★ **ENGINEER**

Each episode, the team or student whose prediction lands closest to the real number wins that round. Score each round with: how close (%) = (prediction – real number) ÷ real number × 100. Ignore the minus sign. Lowest total wins the season. The finals happen at Art Hill (Chapter 08), where the people who did the math watch it get tested.

Episode	My best prediction	The real number	How close (%)
00 · Také Style			
01 · The Empty Bus			
02 · 79 in One			
03 · The Keg Line			
04 · Jump the Zamboni			
05 · The Parade			
06 · The Bend			
07 · The Spirit			
08 · Art Hill			
09 · Center Stage			
10 · The Wash Ave Gap			

Solve it. Don't try it.

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