

HOW TRAINS WORK: PHYSICS & ENGINEERING AT WORK - GRADE 11 & 12 READING

Improve students'
literacy skills

Sub Plan

Science
Applicability



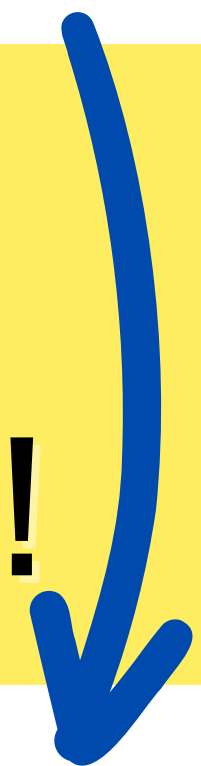
Reading Comment



Extremely satisfied - Great resource to work on student reading comprehension and it tied into the topic I was teaching. My students have been struggling with reading and I've been incorporating more reading into my lessons. Thank you for the resource.



SCROLL
to take a look inside!

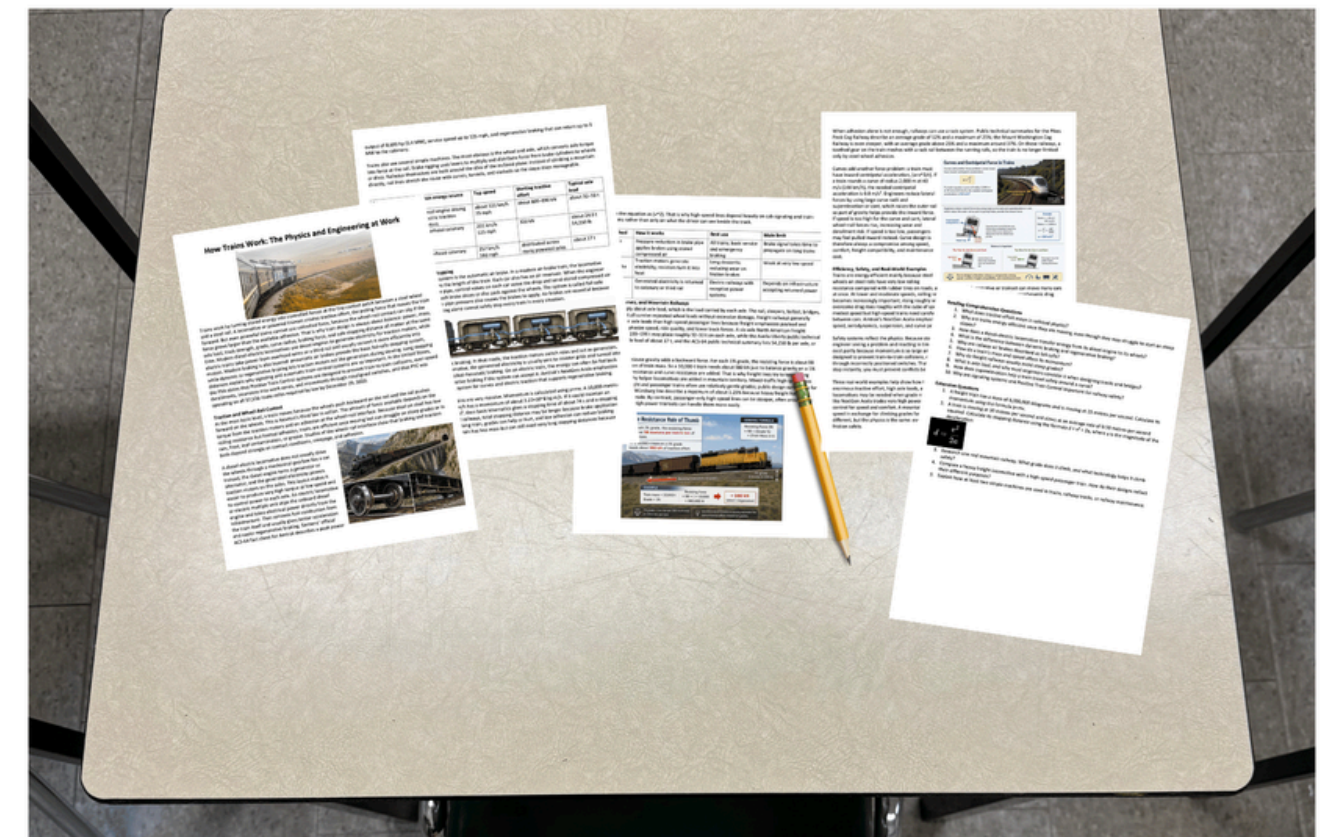


THE PROBLEMS YOU FACE

- **Limited time to teach scientific literacy and strengthen students' reading and analysis skills.**
- **Need meaningful extension activities to engage fast-moving learners.**
- **Difficulty creating effective last-minute sub plans that still support student learning.**

NO-PREP - PRINT/UPLOAD

- **CLASSROOM READY - No Prep, Ready-to-Use:** Print or assign digitally with Google Docs, Microsoft Word, and PDF formats for flexible classroom use
- **Questions and Answer Key**
- **Includes Varied Question Types:** Knowledge, thinking, connecting, application, and open-ended questions.



What Will Your Students Learn?

READING COMPREHENSION ARTICLE & QUESTION BUNDLE

Article with
Comprehension
Questions

Grade 8 and Up

Print & Digital

- Tractive Effort and Wheel–Rail Contact
- Newton’s Third Law and Train Motion
- Torque, Adhesion, and Creepage
- Rolling Resistance and Energy Efficiency
- Diesel-Electric and Electric Locomotives
- Traction Motors and Energy Conversion
- Simple Machines in Railway Engineering
- Pneumatic Air Brakes and Fail-Safe Design
- Momentum and Stopping-Distance Calculations
- Axle Load and Track Infrastructure
- Grade Resistance and Helper Locomotives
- Rack-and-Pinion Mountain Railways
- Centripetal Acceleration, Curves, Superelevation, & Lateral Forces
- Freight vs. High-Speed Passenger Trains

Reading Comprehension Questions

1. What does tractive effort mean in railroad physics?
2. Why are trains energy-efficient once they are moving, even though they may struggle to start on steep slopes?
3. How does a diesel-electric locomotive transfer energy from its diesel engine to its wheels?
4. What is the difference between dynamic braking and regenerative braking?
5. What is a fail-safe system, and how is it described as fail-safe?
- 6.
- 7.
- 8.
- 9.
- 10.

Extended Questions

- 1.
- 2.

How Trains Work: The Physics and Engineering at Work



Trains work by turning stored energy into controlled forces at the tiny contact patch between a steel wheel and a steel rail. A locomotive or powered trainset creates tractive effort, the pulling force that moves the train forward. But even powerful trains cannot use unlimited force, because the wheel–rail contact can slip if the force grows larger than the available adhesion. That is why train design is always about balance: power, mass, axle load, track strength, grade, curve radius, braking force, and safe stopping distance all matter at the same time. Modern diesel-electric locomotives use diesel engines to generate electricity for traction motors, while electric trains take power from overhead wires or a third rail and usually convert it more efficiently into motion. Modern braking is also layered: pneumatic air brakes provide the basic fail-safe stopping system, while dynamic or regenerative braking lets traction motors act like generators during slowing. Long stopping distances explain why signaling and automatic train-control systems are so important. In the United States, the FRA states that Positive Train Control systems are designed to prevent train-to-train collisions, over-speed derailments, incursions into work zones, and movements through misaligned switches, and that PTC was operating on all 57,536 route-miles required by law by December 29, 2020.

Traction and Wheel–Rail Contact

At the most basic level, a train moves because the wheels push backward on the rail and the rail pushes forward on the wheels. This is Newton’s third law in action. The amount of force available depends on the torque from the traction motors and on adhesion at the wheel–rail interface. Because steel on steel has low rolling resistance but limited adhesion, trains are efficient once moving but can struggle on steep grades or in rain, frost, leaf contamination, or grease. Studies of the wheel–rail interface show that braking and traction both depend strongly on contact conditions, creepage, and adhesion.

A diesel-electric locomotive does not usually drive the wheels through a mechanical gearbox like a car. Instead, the diesel engine drives a generator or alternator, which produces electricity. This electricity powers traction motors that turn the wheels. The generator makes electricity from the diesel engine, and the traction motors use that electricity to power the wheels. The diesel engine is connected to the generator, and the generator is connected to the traction motors. The diesel engine is connected to the generator, and the generator is connected to the traction motors.

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Your Reading

How Trains Work: The Physics and Engineering at Work



Trains work by turning stored energy into controlled forces at the tiny contact patch between a steel wheel and a steel rail. A locomotive or powered trainset creates tractive effort, the pulling force that moves the train forward. But even powerful trains cannot use unlimited force, because the wheel–rail contact can slip if the force grows larger than the available adhesion. That is why train design is always about balance: power, mass, axle load, track strength, grade, curve radius, braking force, and safe stopping distance all matter at the same time. Modern diesel-electric locomotives use diesel engines to generate electricity for traction motors, while electric trains take power from overhead wires or a third rail and usually convert it more efficiently into motion. Modern braking is also layered: pneumatic air brakes provide the basic fail-safe stopping system, while dynamic or regenerative braking lets traction motors act like generators during slowing. Long stopping distances explain why signaling and automatic train-control systems are so important. In the United States, the FRA states that Positive Train Control systems are designed to prevent train-to-train collisions, over-speed derailments, incursions into work zones, and movements through misaligned switches, and that PTC was operating on all 57,536 route-miles required by law by December 29, 2020.

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A diesel-electric locomotive does not usually drive the wheels through a mechanical gearbox like a car. Instead, the diesel engine turns a generator or alternator, and the generated electricity powers traction motors on the axles. This layout makes it easier to produce very high torque at low speed and to control power to each axle. An electric locomotive or electric multiple unit skips the onboard diesel engine and takes electrical power directly from the infrastructure. That removes fuel combustion from the train itself and usually gives better acceleration and easier regenerative braking. Siemens' official ACS-64 fact sheet for Amtrak describes a peak power



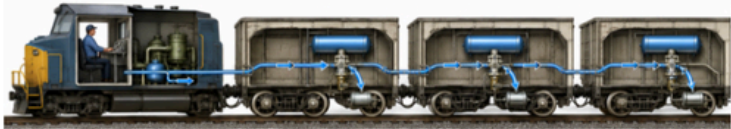
output of 8,600 hp (6.4 MW), service speed up to 125 mph, and regenerative braking that can return up to 5 MW to the catenary.

Trains also use several simple machines. The most obvious is the wheel and axle, which converts axle torque into force at the rail. Brake rigging uses levers to multiply and distribute force from brake cylinders to wheels or discs. Railways themselves are built around the idea of the inclined plane: instead of climbing a mountain directly, rail lines stretch the route with curves, tunnels, and viaducts so the slope stays manageable.

Locomotive or train type	Main energy source	Top speed	Starting tractive effort	Typical axle load
Heavy freight diesel-electric	Diesel engine driving electric traction motors	about 121 km/h 75 mph	about 800–890 kN	about 32–33 t
Intercity electric locomotive	Overhead catenary	201 km/h 125 mph	320 kN	about 24.6 t 54,250 lb
High-speed electric trainset	Overhead catenary	257 km/h 160 mph	distributed across many powered axles	about 17 t

Braking, Momentum, and Stopping

A train's fundamental brake system is the automatic air brake. In a modern air-brake train, the locomotive charges a brake pipe that runs the length of the train. Each car also has an air reservoir. When the engineer reduces pressure in the brake pipe, control valves on each car sense the drop and send stored compressed air into brake cylinders, which push brake shoes or disc pads against the wheels. The system is called fail-safe because a major loss of brake-pipe pressure also causes the brakes to apply. Air brakes are essential because dynamic or regenerative braking alone cannot safely stop every train in every situation.



Many locomotives add dynamic braking. In that mode, the traction motors switch roles and act as generators. On a diesel-electric freight locomotive, the generated electricity is usually sent to resistor grids and turned into heat, which is why this is also called rheostatic braking. On an electric train, the energy can often be fed back to the power system as regenerative braking if the system can accept it. Amtrak's NextGen Acela emphasizes high-speed operation with a tilt system for curves and electric traction that supports regenerative braking.

Momentum matters because trains are very massive. Momentum is calculated using $p=mv$. A 10,000-metric-ton freight train moving at 80 km/h has a momentum of about 2.22×10^8 kg·m/s. If it could maintain an average deceleration of 0.30 m/s^2 , then basic kinematics gives a stopping time of about 74 s and a stopping distance of about 820 m. On real railways, total stopping distance may be longer because brake application takes time to propagate down a long train, grades can help or hurt, and low adhesion can reduce braking force. A much faster passenger train has less mass but can still need very long stopping distances because

speed enters the equation as (v^2) . That is why high-speed lines depend heavily on cab signaling and train-control systems rather than only on what the driver can see beside the track.

Braking method	How it works	Best use	Main limit
Pneumatic air brake	Pressure reduction in brake pipe applies brakes using stored compressed air	All trains; basic service and emergency braking	Brake signal takes time to propagate on long trains
Dynamic or rheostatic brake	Traction motors generate electricity; resistors turn it into heat	Long descents; reducing wear on friction brakes	Weak at very low speed
Regenerative brake	Generated electricity is returned to catenary or third rail	Electric railways with receptive power systems	Depends on infrastructure accepting returned power

Grades, Curves, and Mountain Railways

Railways care deeply about axle load, which is the load carried by each axle. The rail, sleepers, ballast, bridges, and subgrade must all survive repeated wheel loads without excessive damage. Freight railways generally accept much higher axle loads than high-speed passenger lines because freight emphasizes payload and passenger lines emphasize speed, ride quality, and lower track forces. A six-axle North American freight locomotive around 193–196 t may place roughly 32–33 t on each axle, while the Avelia Liberty public technical summary lists an axle load of about 17 t, and the ACS-64 public technical summary lists 54,250 lb per axle, or about 24.6 t.

Grades are critical because gravity adds a backward force. For each 1% grade, the resisting force is about 98 newtons per metric ton of train mass. So a 10,000-t train needs about 980 kN just to balance gravity on a 1% grade, before rolling resistance and curve resistance are added. That is why freight lines try to keep ruling grades modest and why helper locomotives are added in mountain territory. Mixed-traffic high-speed lines designed for both freight and passenger trains often use relatively gentle grades; public design summaries for Germany's Hannover–Würzburg line describe a maximum of about 1.25% because heavy freight had to be able to restart on the grade. By contrast, passenger-only high-speed lines can be steeper, often around 2.5–5%, because lighter, high-power trainsets can handle them more easily.



When adhesion alone is not enough, railways can use a rack system. Public technical summaries for the Mount Washington Railway describe an average grade of 12% and a maximum of 25%; the Mount Washington Railway is even steeper, with an average grade above 25% and a maximum around 37%. On the toothed gear on the train meshes with a rack rail between the running rails, so the train is no longer held only by steel-wheel adhesion.

Curves add another force problem: a train must have inward centripetal acceleration, $(a=v^2/r)$. If a train rounds a curve of radius 2,000 m at 40 m/s (144 km/h), the needed centripetal acceleration is 0.8 m/s^2 . Engineers reduce lateral forces by using large curve radii and superelevation or cant, which raises the outer rail so part of gravity helps provide the inward force. If speed is too high for the curve and cant, lateral wheel–rail forces rise, increasing wear and derailment risk. If speed is too low, passengers may feel pulled inward instead. Curve design is therefore always a compromise among speed, comfort, freight compatibility, and maintenance cost.

Efficiency, Safety, and Real-World Examples

Trains are energy-efficient mainly because steel wheels on steel rails have very low rolling resistance compared with rubber tires on roads, and because one locomotive or trainset can move many cars at once. At lower and moderate speeds, rolling resistance dominates, but at higher speeds, aerodynamics becomes increasingly important, rising roughly with the square of speed, while the power needed to overcome drag rises roughly with the cube of speed. That is why blunt freight trains can still be economical at modest speed but high-speed trains need carefully shaped noses, smooth underbodies, and sealed doors. Amtrak's NextGen Acela emphasizes high-speed operation with 160 mph operation and a tilt system, so speed, aerodynamics, suspension, and curve performance are designed together.

Safety systems reflect the physics. Because stopping distances are long, railways cannot rely on an engineer seeing a problem and reacting in time. Signals, cab displays, train-control systems exist partly because momentum is so large and braking takes so much distance. FRA standards designed to prevent train-to-train collisions, overspeed derailments, work-zone incursions through incorrectly positioned switches. That is a direct answer to the physics of railroad safety: you must prevent conflicts before they happen.

Three real-world examples help show how the physics changes with mission. A heavy freight train needs enormous tractive effort, high axle loads, and often dynamic braking for mountain descents. Locomotives may be needed when grade resistance overwhelms the lead units. A high-speed train like NextGen Acela trades very high power, lower axle load, sophisticated suspension, an control for speed and comfort. A mountain rack railway like Pikes Peak or Mount Washington trades speed in exchange for climbing grades far beyond the limit of ordinary adhesion railways, but the physics is the same: every train is a machine built to manage force, energy, and friction safely.

Reading Comprehension Questions

1. What does tractive effort mean in railroad physics?
2. Why are trains energy-efficient once they are moving, even though they may struggle to start on steep slopes?
3. How does a diesel-electric locomotive transfer energy from its diesel engine to its wheels?
4. What is the difference between dynamic braking and regenerative braking?
5. Why are railway air brakes described as fail-safe?
6. How do a train's mass and speed affect its momentum?
7. Why do freight railways usually avoid steep grades?
8. What is axle load, and why must engineers consider it when designing tracks and bridges?
9. How does superelevation help a train travel safely around a curve?
10. Why are signaling systems and Positive Train Control important for railway safety?

Extension Questions

1. A freight train has a mass of 6,000,000 kilograms and is moving at 25 metres per second. Calculate its momentum using the formula $p=mv$.
2. A train is moving at 25 metres per second and slows at an average rate of $0.50 \text{ metres per second squared}$. Calculate the stopping distance using the formula $d = v^2 / 2a$, where a is the magnitude of the deceleration.

$$d = \frac{v^2}{2a}$$

3. Research one real mountain railway. What grade does it climb, and what technology helps it climb safely?
4. Compare a heavy freight locomotive with a high-speed passenger train. How do their designs reflect their different purposes?
5. Explain how at least two simple machines are used in trains, railway tracks, or railway maintenance.

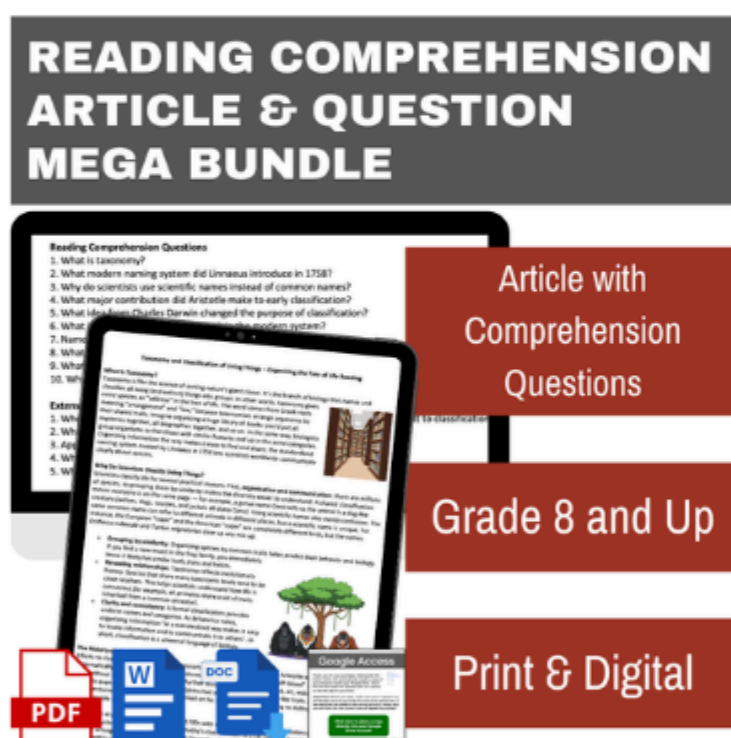
Full Answer Key

Comprehension and Extension Questions



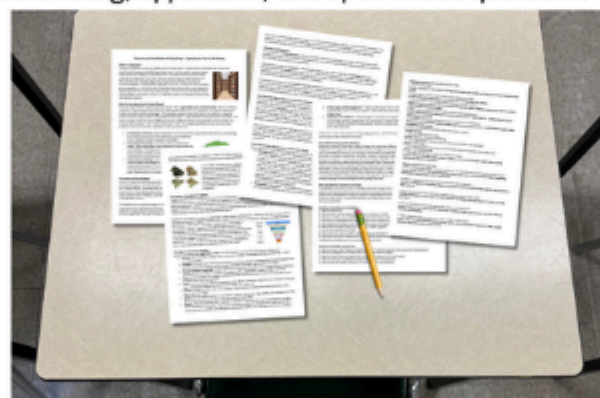
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- **Includes Varied Question Types:** Knowledge, thinking, connecting, application, and open-ended questions.



★★★★★ Extremely satisfied - It is a good supplemental activity either for review and at the same time introducing some concept. I also use this for sub plan. It is well presented, organized and interesting.

★★★★★ Extremely satisfied - This a great resource. I used this for a sub plan. It was fun and engaging for my students.

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ALL my current and future grade 8 and up readings, covering the following subject areas:

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