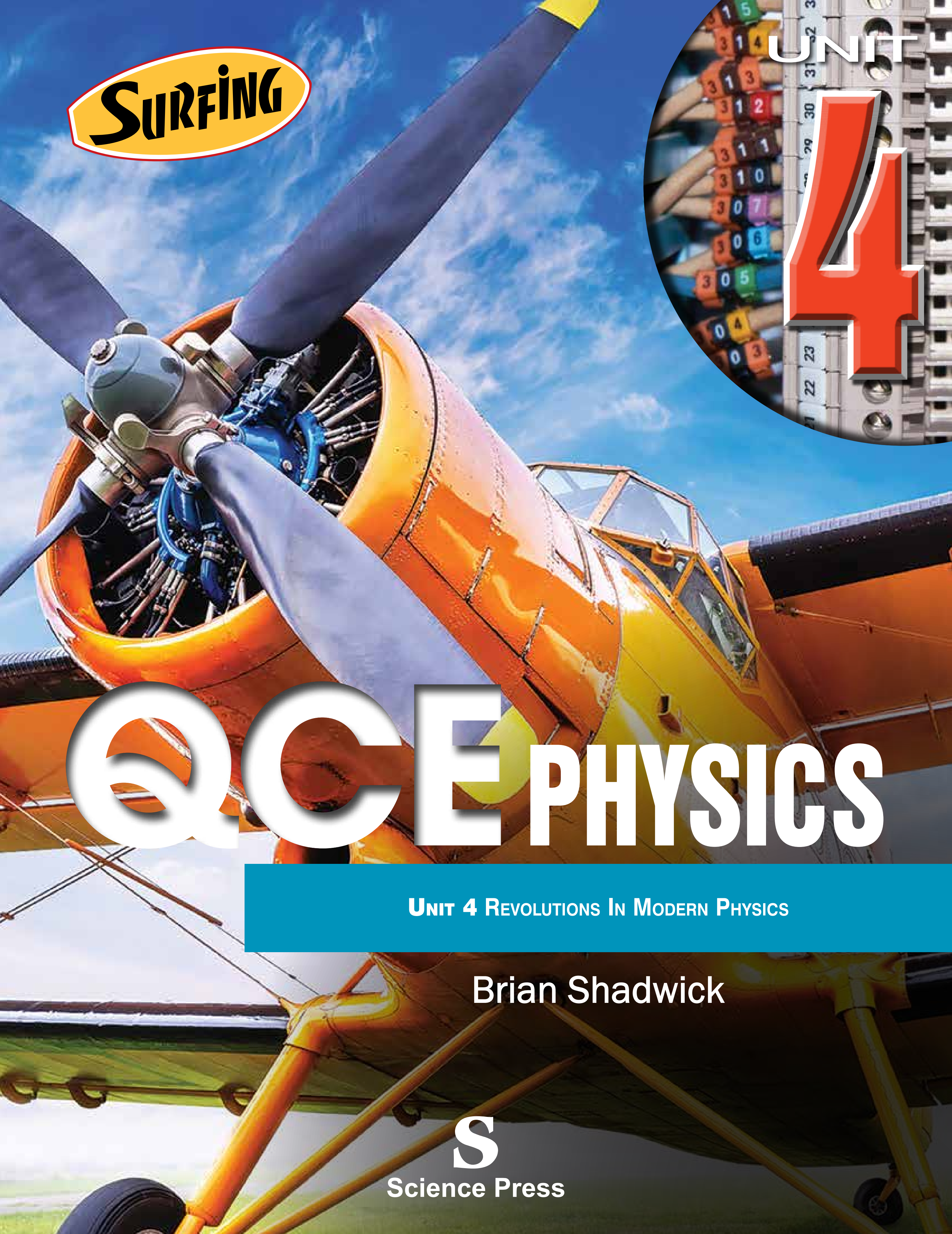

SURFING

UNIT 4

QCE PHYSICS

UNIT 4 REVOLUTIONS IN MODERN PHYSICS

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Contents

Topic 8 Special Relativity

Special Relativity

Define the terms frame of reference and inertial frame of reference.

Recall that motion can only be measured relative to an observer.

Recall the consequences of the constant speed of light in a vacuum, e.g. time dilation and length contraction.
Recall the two postulates of special relativity.

Define time dilation, proper time interval and relativistic time interval including examples of experimental evidence of the phenomena.
Solve problems involving time dilation.

Define length contraction, proper length and relativistic length including examples of experimental evidence of the phenomena.
Solve problems involving length contraction.

Explain paradoxical scenarios such as the twins' paradox.

Explain the concept of simultaneity.
Explain paradoxical scenarios such flashlights on a train.

Explain paradoxical scenarios such as the ladder in the barn paradox.

Describe an example of natural phenomena that cannot be explained by Newtonian physics, such as the presence of muons in the atmosphere.

Define rest mass and relativistic momentum including examples of experimental evidence of the phenomena.
Explain why no object can travel at the speed of light in a vacuum.
Solve problems involving time dilations, length contraction and relativistic momentum.

Recall the mass-energy equivalence relationship.

SCIENCE AS A HUMAN ENDEAVOUR

The human endeavour subject matter will not be assessed in the external examination, but could be used in the development of claims and questions for a research investigation.
The material contained within the book should be considered only as a start for any research task you undertake in these areas.

SCIENCE AS A HUMAN ENDEAVOUR:
Development of the special theory of relativity: Albert Einstein's work on special relativity built upon the work of scientists such as Maxwell and Lorentz, while subsequent studies by Max Planck, Hermann Minkowski and others led to the development of relativistic theories of gravitation, mass-energy equivalence and quantum field theory.

SCIENCE AS A HUMAN ENDEAVOUR:
Ring laser gyroscopes and navigation: Ring laser gyroscopes (RLG) are inertial guidance systems that do not rely on signals from an external source, but from instruments on board a moving object and are used in helicopters, ships, submarines and missiles for accurate navigation.

SCIENCE AS A HUMAN ENDEAVOUR:
Nuclear reactors: Special relativity leads to the idea of mass-energy equivalence, which has been applied in nuclear fission reactors.

Topic 9 Quantum Theory

Quantum Theory

Explain how Young's double slit experiment provides evidence for the wave model of light.

Describe light as an electromagnetic wave produced by an oscillating electric charge that produces mutually perpendicular oscillating electric fields and magnetic fields.

Explain the concept of black body radiation.
Identify that black body radiation provides evidence that electromagnetic radiation is quantised into discrete values.
Recall that photons exhibit the characteristics of both waves and particles.

Describe the concept of a photon.
Describe the photoelectric effect in terms of the photon.
Define the terms threshold frequency, Planck's constant and work function.
Describe wave-particle duality of light by identifying evidence that supports the wave characteristics of light and evidence that supports the particle characteristics of light.

Solve problems involving the energy, frequency and wavelength of a photon.

Solve problems involving the photoelectric effect.

Mandatory practical – Conduct an experiment (or use a simulation) to investigate the photoelectric effect. Data such as the photoelectron energy or velocity, or electrical potential difference across the anode and cathode, can be compared with the wavelength or frequency of incident light. Calculation of work functions and Planck's constant using the data would also be appropriate.

Describe Rutherford's model of the atom including its limitations.

Describe the Bohr model of the atom and how it addresses the limitations of Rutherford's model.

Explain how the Bohr model of the hydrogen atom integrates light quanta and atomic energy states to explain the specific wavelengths in the hydrogen line spectrum.
Solve problems involving the line spectra of simple atoms using atomic energy states or atomic energy level diagrams.

SCIENCE AS A HUMAN ENDEAVOUR

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SCIENCE AS A HUMAN ENDEAVOUR:
You could explore the historical development of the model of the atom in terms of traditional models, e.g. Democritus, Dalton, Brownian motion, Thomson, Rutherford and Bohr.

SCIENCE AS A HUMAN ENDEAVOUR:
You could research how theories are contested, refined or replaced when new evidence challenges them, or when a new model or theory has greater explanatory power, for example, how can the approximation of Earth as a black body be used to predict climate patterns or what are the problems scientists face in validating their models.
Development of the quantum model: How can the quantum mechanical model of the atom, developed from work by Rutherford, Bohr, Planck and Einstein, be used to explain many observations made about atoms.
Black body radiation and the greenhouse effect: How do models of Earth's energy balance using the concept of black body radiation enable scientists to monitor changes in global temperature, assess the evidence for changes in climate due to the enhanced greenhouse effect and evaluate the risk posed by anthropogenic climate change?

Topic 10 The Standard Model

The Standard Model

Define the concept of an elementary particle and antiparticle.

Recall the six types of quarks.
Define the terms baryon and meson.

Recall the six types of leptons.

Recall the four gauge bosons.
Describe the strong nuclear, weak nuclear and electromagnetic forces in terms of the gauge bosons.
Contrast the fundamental forces experienced by quarks and leptons.

Particle Interactions

Define the concept of lepton number and baryon number.
Recall the conservation of lepton number and baryon number in particle interactions.

Explain the following interactions of particles using Feynman diagrams: electron and electron, electron and positron, and a neutron decaying into a proton.

Describe the significance of symmetry in particle interactions.

SCIENCE AS A HUMAN ENDEAVOUR

The human endeavour subject matter will not be assessed in the external examination, but could be used in the development of claims and questions for a research investigation. The material contained within the book should be considered only as a start for any research task you undertake in these areas.

SCIENCE AS A HUMAN ENDEAVOUR:
You could explore the history of particle physics models and theories through the development of particle accelerators and contributions from notable physicists.

SCIENCE AS A HUMAN ENDEAVOUR:
Evidence for the Higgs boson particle: The Large Hadron Collider was built to test particle physics theories and specifically to try to produce and detect the Higgs boson particle.
Particle accelerators: The construction of the Australian Synchrotron (a particle accelerator) involved collaboration between Australian and New Zealand science organisations, state and federal governments, and international organisations and committees, including the International Science Advisory Committee and the International Machine Advisory Committee.

SCIENCE AS A HUMAN ENDEAVOUR:
The Big Bang theory: There is a variety of evidence that supports the Big Bang theory, including cosmic background radiation, the abundance of light elements, and the red shift of light from galaxies that obey Hubble's law.

Introduction

This book covers the Physics content specified in the Queensland Certificate of Education Physics Syllabus. Sample data has been included for suggested experiments to give you practice to reinforce practical work in class.

Each book in the *Surfing* series contains a summary, with occasional more detailed sections, of all the mandatory parts of the syllabus, along with questions and answers.

All types of questions – multiple choice, short response, structured response and free response – are provided. Questions are written in exam style so that you will become familiar with the concepts of the topic and answering questions in the required way.

Answers to all questions are included.

A topic test at the end of each topic contains an extensive set of summary questions. These cover every aspect of the topic, and are useful for revision and exam practice.

Words To Watch

account, account for State reasons for, report on, give an account of, narrate a series of events or transactions.

analyse Interpret data to reach conclusions.

annotate Add brief notes to a diagram or graph.

apply Put to use in a particular situation.

assess Make a judgement about the value of something.

calculate Find a numerical answer.

clarify Make clear or plain.

classify Arrange into classes, groups or categories.

comment Give a judgement based on a given statement or result of a calculation.

compare Estimate, measure or note how things are similar or different.

construct Represent or develop in graphical form.

contrast Show how things are different or opposite.

create Originate or bring into existence.

deduce Reach a conclusion from given information.

define Give the precise meaning of a word, phrase or physical quantity.

demonstrate Show by example.

derive Manipulate a mathematical relationship(s) to give a new equation or relationship.

describe Give a detailed account.

design Produce a plan, simulation or model.

determine Find the only possible answer.

discuss Talk or write about a topic, taking into account different issues or ideas.

distinguish Give differences between two or more different items.

draw Represent by means of pencil lines.

estimate Find an approximate value for an unknown quantity.

evaluate Assess the implications and limitations.

examine Inquire into.

explain Make something clear or easy to understand.

extract Choose relevant and/or appropriate details.

extrapolate Infer from what is known.

hypothesise Suggest an explanation for a group of facts or phenomena.

identify Recognise and name.

interpret Draw meaning from.

investigate Plan, inquire into and draw conclusions about.

justify Support an argument or conclusion.

label Add labels to a diagram.

list Give a sequence of names or other brief answers.

measure Find a value for a quantity.

outline Give a brief account or summary.

plan Use strategies to develop a series of steps or processes.

predict Give an expected result.

propose Put forward a plan or suggestion for consideration or action.

recall Present remembered ideas, facts or experiences.

relate Tell or report about happenings, events or circumstances.

represent Use words, images or symbols to convey meaning.

select Choose in preference to another or others.

sequence Arrange in order.

show Give the steps in a calculation or derivation.

sketch Make a quick, rough drawing of something.

solve Work out the answer to a problem.

state Give a specific name, value or other brief answer.

suggest Put forward an idea for consideration.

summarise Give a brief statement of the main points.

synthesise Combine various elements to make a whole.

Surfing

QCE Physics

UNIT 4

UNIT 4

Thermal, Nuclear and Electrical Physics

In this unit you will:

- Examine observations of relative motion, light and matter that could not be explained by classical physics theories.
- Investigate how the shortcomings of existing theories led to the development of the special theory of relativity and the quantum theory of light and matter.
- Evaluate the contribution of the quantum theory of light to the development of the quantum theory of the atom.
- Examine the standard model of particle physics and how it relates to the Big Bang theory.
- Participate in a range of experiments and investigations.

Surfing QCE Physics

UNIT 4

TOPIC 8

Special Relativity

In this topic you will:

- Explore natural phenomena that cannot be explained by Newtonian physics.
- Become familiar with terms such as frames of reference, time intervals, proper and relativistic length, and rest mass.
- Learn about the two postulates of special relativity and realise that motion can only be measured relative to the observer.
- Solve problems involving time dialation, length contraction and relativistic momentum.
- Examine the mass-energy equivalence relationship.
- Understand why no object can travel at the speed of light in a vacuum as well as paradoxical scenarios such as the twins' paradox, flashlights on a train and the ladder in the barn paradox.

1 Frames Of Reference and the Principle Of Relativity

A **frame of reference** is a system of coordinates in which we make measurements and observations.

The principle of relativity

You will have heard the expression ‘all motion is relative’. In physics this refers to the **special principle of relativity**, (usually referred to as just the **principle of relativity**) and to the fact that constant velocity motion cannot be detected unless we have a frame of reference to compare it to.

If you are in a spaceship, plane – whatever – and the motion is constant and steady, you cannot tell if you are moving (or not moving) unless you look out a window and see something changing outside. At this very moment you cannot feel that you are moving through space at 30 km s^{-1} – the orbital speed of the Earth – because you have no frame of reference to judge that motion by. This idea is known as the **principle of relativity** and it holds true for any frame of reference that is not accelerating.

Inertial frames of reference

A frame of reference that is not accelerating is known as an **inertial frame of reference**. Motion cannot be detected in an inertial frame of reference.

Inertial frames of reference include:

- Any frame of reference which is at rest.
- Any frame of reference which is moving at constant velocity.
- Any frame of reference which is in a stable, constant speed orbit (more correctly referred to as a ‘free float’) orbit, such as Earth or the space station.

Non-inertial frames of reference

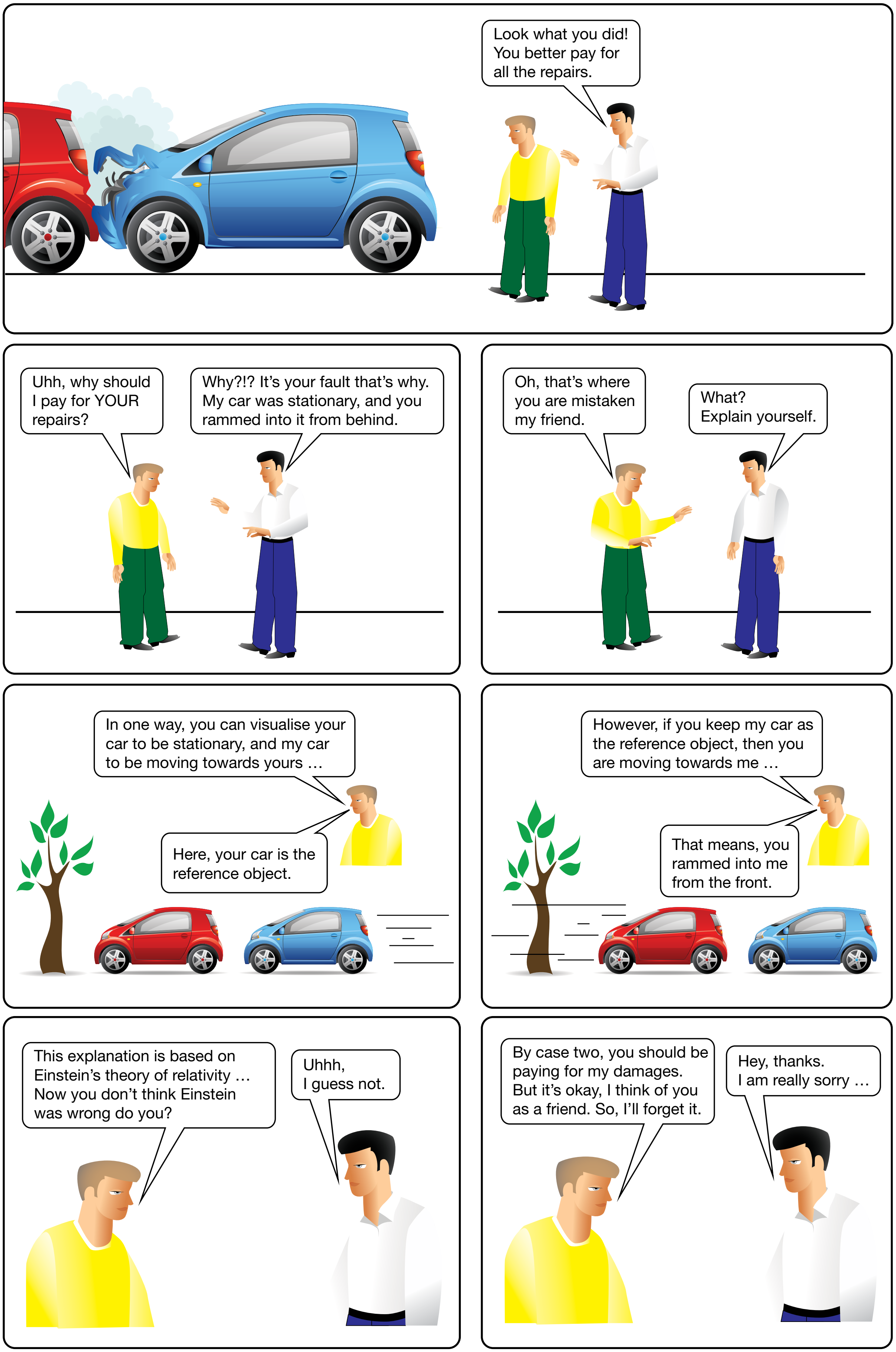
Motion *is* detectable in a **non-inertial frame of reference** – one which is accelerating. If a plane is accelerating you can feel reaction forces. If a car accelerates ahead or turns a corner, you feel it. **The principle of relativity does not hold in a non-inertial frame of reference**.

Light presented a problem

During the 19th century, while the principle of relativity was accepted for most events, scientists were concerned about light and how it travelled. The aether theory they developed for light (light is propagated through an extremely low density, invisible particle medium) included the idea that measurements of the speed of light made from an object moving with constant velocity would give different values, depending on which way the object was moving relative to the aether.

These measurements would enable the observer to determine that they were making their measurements in an inertial frame of reference. This idea violated the principle of relativity (constant motion cannot be detected without reference to a fixed position outside the frame of reference) and caused scientists like Albert Einstein, who held that the principle of relativity could never be violated, to work towards a new theory for light.

He started thinking about a model for motion that would also be applicable to light. By analysing several ‘**thought experiments**’, he devised and put forward his **special theory of relativity** 10 years later. Einstein’s theories did not prove or disprove the existence of the aether – they simply made its existence unnecessary. Over time, scientists gradually dismissed it as an idea.



Look what you did! You better pay for all the repairs.
Uhh, why should I pay for YOUR repairs?
Why?!? It's your fault that's why. My car was stationary, and you rammed into it from behind.
Oh, that's where you are mistaken my friend.
What? Explain yourself.
In one way, you can visualise your car to be stationary, and my car to be moving towards yours …
Here, your car is the reference object.
However, if you keep my car as the reference object, then you are moving towards me …
That means, you rammed into me from the front.
This explanation is based on Einstein's theory of relativity … Now you don't think Einstein was wrong do you?
Uhhh, I guess not.
By case two, you should be paying for my damages. But it's okay, I think of you as a friend. So, I'll forget it.
Hey, thanks. I am really sorry …

QUESTIONS

1. Clarify the idea of a frame of reference and identify your most common frame of reference.
2. Classify each of the following as an inertial or non-inertial frame of reference and explain your choice.
   (a) The Earth.
   (b) Your school laboratory.
   (c) A plane in level, constant flight.
   (d) A plane in a steep climb.
   (e) The school bus turning a corner.
   (f) A roller coaster.
   (g) A spaceship in geostationary orbit.
3. Explain the essential difference between an inertial frame of reference and a non-inertial frame of reference.
4. Recall the special principle of relativity.
5. An astronaut tied his mascot to a string and hung it from the ceiling of his spaceship. One day he noticed that, instead of hanging straight down, it hung at an angle.
   (a) Account for this.
   (b) Identify the frame of reference the mascot is in when it hangs straight down. Justify your answer.
   (c) Identify the frame of reference it is in when it hangs at an angle, and justify your answer.
6. Giving an appropriate example, discuss why it is important for us to consider our frame of reference when we make measurements.
7. (a) You regain consciousness some time after an asteroid hit your spaceship. You are unaware of any movement of the craft. You wonder if you are still on course and moving towards Andromeda galaxy. Suddenly a comet shoots past you, seemingly parallel to your path and moving straight ahead. Which of the following interpretations of this observation is *not* possible?
      (A) Both you and the comet are travelling towards Andromeda, but the comet is moving faster than you.
      (B) You are stationary and the comet is moving past you towards Andromeda.
      (C) You are moving backwards and the comet is moving towards Andromeda.
      (D) You are moving towards Andromeda and the comet is moving away from Andromeda.
   (b) Give two other possible interpretations of this observation.

8. What best summarises the characteristics of an inertial frame of reference?
   (A) It is stationary.
   (B) It is moving with constant velocity.
   (C) It is not turning a corner.
   (D) It is accelerating.
9. A spaceship in a stable orbit around a planet is an inertial frame of reference despite the fact that it is travelling in a circular path and therefore has an acceleration towards the centre of the orbit. Why?
   (A) Its acceleration is negligible.
   (B) The centripetal force is balanced by the gravitational force.
   (C) Because there are no inertial forces acting on it.
   (D) It is moving with constant velocity.

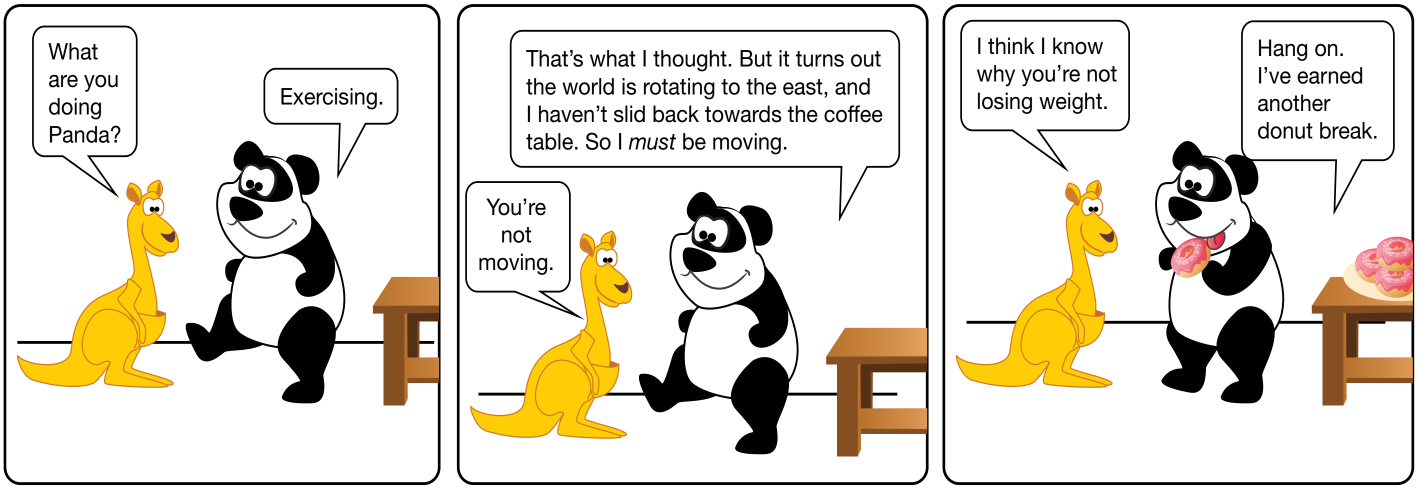
2 Galilean Transformations

A Galilean transformation is one in which normal mathematics can be applied to determine relative motion – that is, the motion of one object relative to another. It compares motion in different frames of reference using only Newtonian physics and ignores relativistic effects.

Galilean transformations only hold at low speeds where relativistic effects can be ignored. If objects are moving at significant proportions of light speed the relativistic effects must be considered, so a simple Galilean transformation would be invalid.

Galilean transformations can be analysed using the mathematical formulas developed by Galileo and Newton. Galilean transformations cover the motion of most objects larger than atoms.

When we come to study the motion of objects moving at significant proportions of the speed of light, especially those associated with experiments in particle accelerators, then Galilean transformations are not accurate enough. We then have to use Einstein's relativistic mathematics.

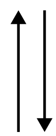
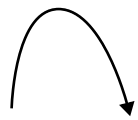
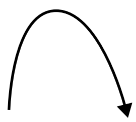
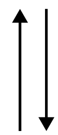
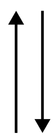
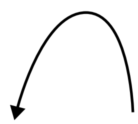
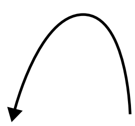
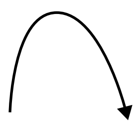


QUESTIONS

1. Describe what we mean by a Galilean transformation.
2. In what situations do Galilean transformations not hold? Explain your answer.
3. Object X is moving east at 30 m s^{-1}. Object Y is moving west at 25 m s^{-1}. Object Z is moving east at 15 m s^{-1}. Calculate the velocity of:
   (a) X relative to Y.
   (b) X relative to Z.
   (c) Y relative to X.
   (d) Y relative to Z.
   (e) Z relative to X.
   (f) Z relative to Y.
4. From your answers to Question 3 above, identify the relationship between the velocity of object A relative to object B and the velocity of object B relative to object A.
5. Object X is moving east at 24 m s^{-1}. Object Y is moving north at 18 m s^{-1}. With the aid of an appropriate vector diagram, calculate the velocity of:
   (a) X relative to Y.
   (b) Y relative to X.

6. Car A is travelling south at 55 m s^{-1}. Car B is travelling north at 25 m s^{-1}. Calculate the velocity of:
(a) A relative to B.
(b) B relative to A.

7. (a) A student in a bus which is moving at constant velocity from the left to the right throws a ball straight up into the air. The path the ball follows is observed by Michael inside the bus and by Christian outside the bus.

	Michael sees:	Christian sees:
(A)		
(B)		
(C)		
(D)		

Which diagrams show what each sees?
(b) What type of frame of reference is each observer in?

8. A pilot wishes to fly at maximum speed due north. The plane can fly at 100 km h^{-1} in still air. A 30 km h^{-1} wind blows from the south-east. Calculate:
(a) The direction the plane must head to fly north.
(b) Its speed relative to the ground.

9. Chris, who can swim at 1.6 m s^{-1} in still water, dives into a river at X and swims towards Y directly opposite in a northerly direction. The river flows at 1.2 m s^{-1} east.
Calculate the velocity of:
(a) The water relative to the bank.
(b) Chris relative to the water.
(c) Chris relative to the bank.

10. A person can row a boat at 1.75 m s^{-1} in still water. He rows on a river which flows at 0.45 m s^{-1}.
(a) Calculate the velocity of the person relative to the banks of the river if he rows parallel to the bank:
(i) With the flow.
(ii) Against the flow.
(b) Calculate the velocity of the boat relative to the water if he rows:
(i) With the flow.
(ii) Against the flow.

11. A river is flowing at 3.75 m s^{-1}. A person in a canoe can row at 4.25 m s^{-1}. The person rows the canoe for 5 minutes as part of a training routine.
Calculate how far the person would have rowed (relative to the bank) if the direction of rowing was parallel to the bank and:
(a) Against the flow.
(b) With the flow.

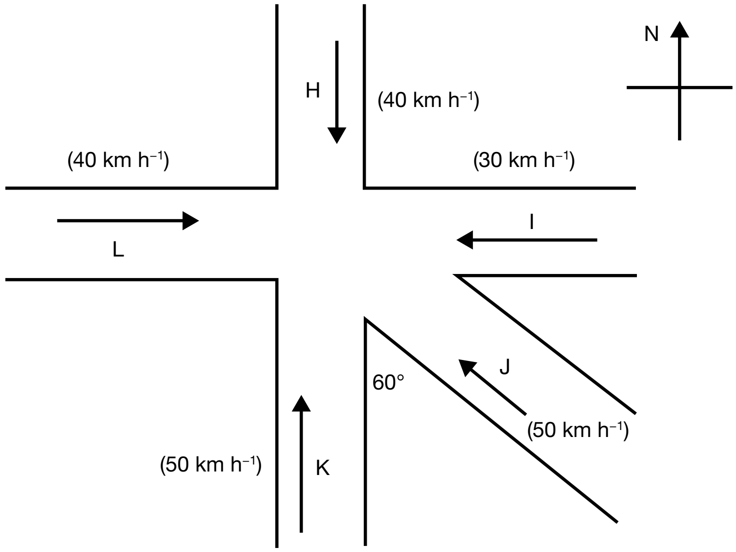
12. A plane is flying north at 200 km h^{-1} when it encounters a 30 km h^{-1} wind from the south-west.
Calculate:
(a) The velocity of the wind relative to the ground.
(b) The velocity of the wind relative to the plane.
(c) The velocity of the plane relative to the ground after it encounters the wind.
(d) The new course the plane must fly to head north.
(e) The speed of the plane when it is heading north again.

13. A boat, capable of travelling at 15 m s^{-1} in still water sets out to travel from P to Q a distance of 450 m due north. A current flows from the west at 5 m s^{-1}.
Calculate:
(a) The direction the boat takes to move directly from P to Q.
(b) Its speed relative to the water.
(c) Its speed relative to the ground.
(d) How long it will take to make the journey.

14. A pilot wishes to fly at maximum speed due north. The plane can fly at 350 km h^{-1} in still air. A 90 km h^{-1} wind blows from the west. Calculate:
(a) The direction the plane must head to fly north.
(b) Its speed relative to the ground.

15. Anne, who can swim at 1.5 m s^{-1} in still water, dives into a river at X and swims towards Y directly opposite in a northerly direction. The river flows at 0.9 m s^{-1} west.
Calculate:
(a) The velocity of the water relative to the bank.
(b) Anne's velocity relative to the water.
(c) Anne's velocity relative to the bank.

16. A boat, capable of travelling at 20 m s^{-1} in still water sets out to travel from P to Q a distance of 600 m due west. A current flows from the south at 8 m s^{-1}. Calculate:
   (a) The direction the boat takes to move directly from P to Q.
   (b) Its speed relative to the water.
   (c) Its speed relative to the ground.
   (d) How long it will take to make the journey.
17. A plane is flying due north at 450 km h^{-1} despite a crosswind of 80 km h^{-1} from the east.
   (a) What is the direction the pilot must head the plane in order to achieve this?
   (b) What would be its speed relative to the ground in still air?
18. The diagram shows several cars approaching an intersection.
   Use the information in the diagram to complete the table below to show the relative velocity of each car to each other car.
   The diagram has not been drawn to scale.



Velocity of … / Relative to …	H	I	J	K	L
H	....				
I		....			
J			....		
K				....	
L					....

Recall the consequences of the constant speed of light in a vacuum, e.g. time dilation and length contraction. Recall the two postulates of special relativity.

3 Einstein's First Thought Experiment

Einstein's special theory of relativity is based on two postulates:

- The speed of light in a vacuum is an absolute constant.
- All inertial frames are equivalent.

Both of these postulates are a direct result of his belief that the principle of relativity cannot be violated. His mental processes in coming to these conclusions are summarised in his thought experiments.

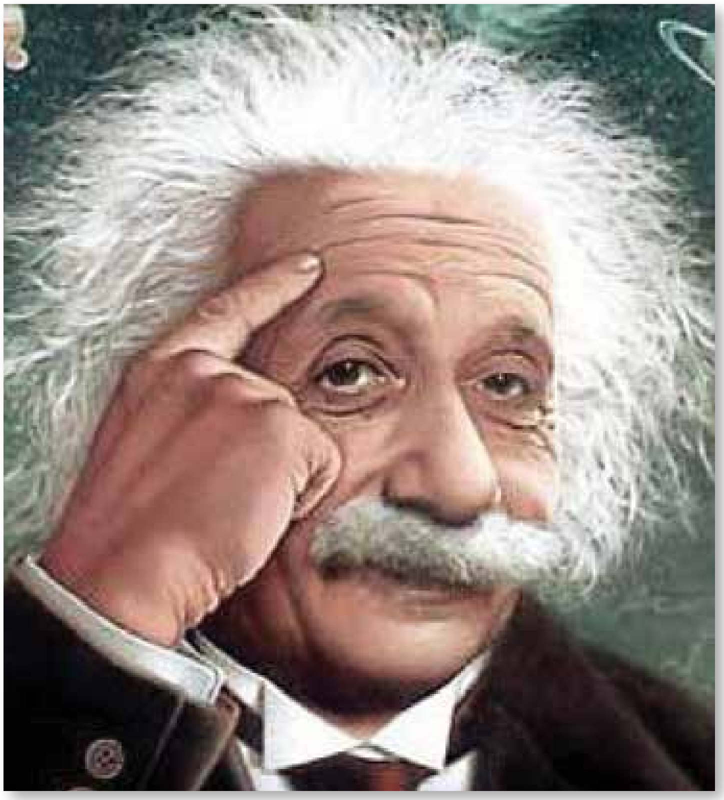
In his first though experiment Einstein wondered:

'Suppose I am sitting in a train travelling at the speed of light. If I hold a mirror in front of me, will I see my reflection?'

There are two possibilities:

No. If the train is travelling at the speed of light, light from his face would not reach the mirror in order to be reflected back. By not being able to see his reflection, he would know that the train was travelling at the speed of light *without having to refer to an outside point*. This violates the principle of relativity.

Yes. This means that light would travel at its normal speed *relative to the train*. This does not violate the principle of relativity. However, it also means that, relative to a stationary observer outside the train, light would have to travel at twice its usual speed!



Einstein's conclusions

After considering this problem with friends over the next ten years, Einstein eventually concluded that, if the principle of relativity can never be violated, then:

- The aether model for light must be wrong.
- He would see his reflection.
- The speed of light is constant regardless of the motion of the observer.

In order to satisfy this third decision he made a revolutionary statement:

It is not the speed of light that is changing, but **time**.

In other words, stationary and moving observers see space and time differently.

In classical physics space and time are constants and motion is defined by them. In Einstein's physics it is the speed of light that is constant and space and time change to accommodate this.

Using these ideas, Einstein put forward his special theory of relativity.

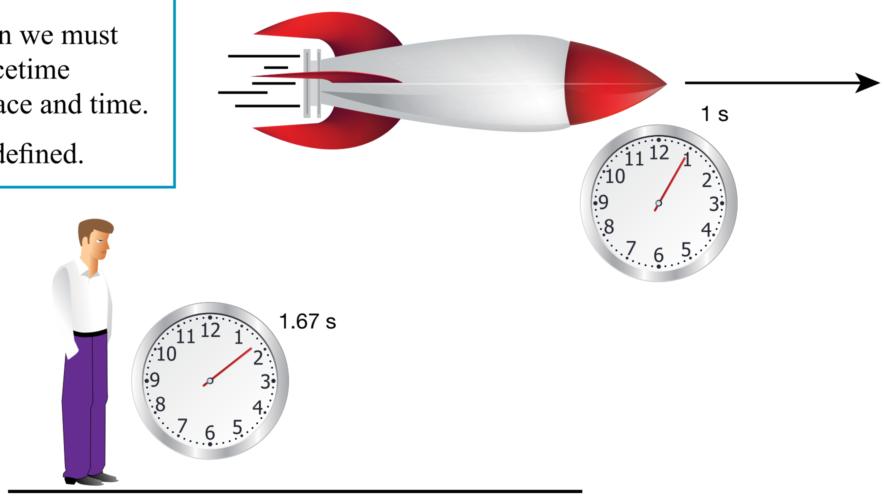
Special theory of relativity
All motion is relative – the principle of relativity holds in all situations. The speed of light is constant regardless of the observer's frame of reference. The aether is not needed to explain the propagation of light, and, in fact, does not exist.

Some consequences of Einstein's special theory

Length and time can no longer be regarded as separate concepts.

In order to define an object's position we must consider *four* coordinates in the spacetime continuum – three dimensions of space and time.

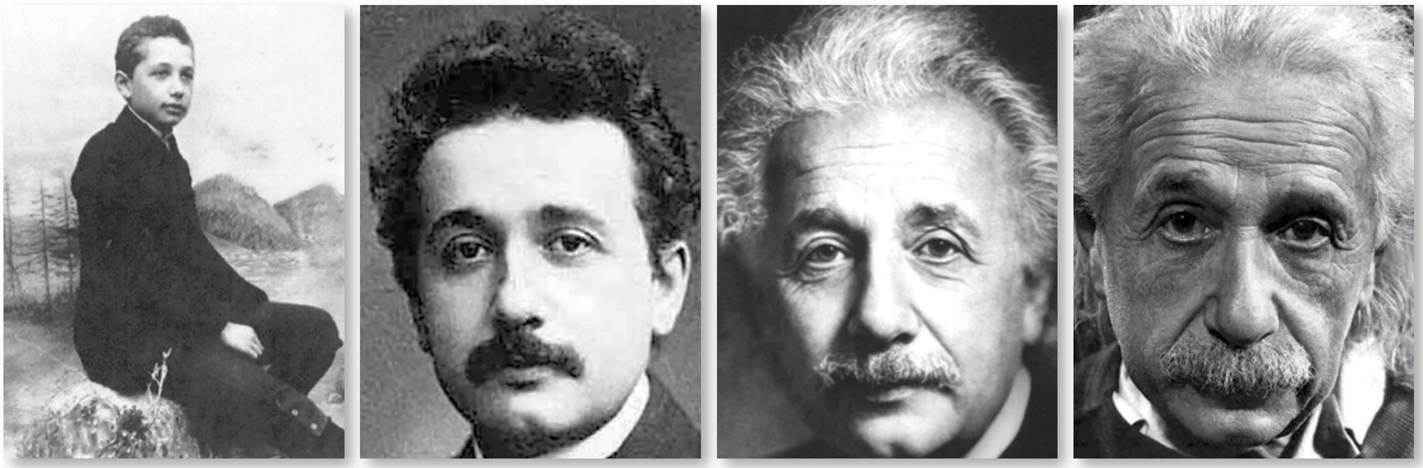
A new standard of length had to be defined.



A stationary observer measures time passing for a moving object as being different to his own.

QUESTIONS

1. State the principle of relativity, and the consequence this has for inertial frames of reference.
2. What was the question Einstein wanted to answer in his first thought experiment?
3. Outline the two possible answers to his problem, and explain how each answer contradicted existing ideas.
4. Outline how Einstein explained this dilemma.
5. Outline how this thought experiment changed scientists' ideas about the relationship between space and time.
6. Explain why/when we have to consider time as well as space when we describe an object.
7. Explain why it was necessary to change the way we define the standard for measuring length.



Time is relative!

8. Research data for the old and the new standards of length.
9. What were the two postulates on which Einstein based his special theory of relativity?
10. Comment on the value of a thought experiment as a legitimate tool in the scientific method.
11. Einstein had no experimental evidence to support or verify his ideas. Does this mean his theory is of less value?
12. Experimental evidence for Einstein's work was not obtained until the 1950s. What was the main problem in being able to obtain this evidence?

Topic 8 Test

For each question, choose the most correct answer.

1. Which scientist first proposed the principle of relativity?
   (A) Albert Einstein.
   (B) Galileo Galilei.
   (C) James Clerk Maxwell.
   (D) Isaac Newton.
2. What was the main difference in the thinking of Galileo and Newton in their ideas about frames of reference?
   (A) Galileo proposed that there was no absolute reference frame while Newton's ideas were based on the existence of an absolute frame of reference.
   (B) Newton proposed that there was no absolute reference frame while Galileo's ideas were based on the existence of an absolute frame of reference.
   (C) Galileo did not develop a set of equations to describe his ideas while Newton did.
   (D) Newton's ideas referred to objects travelling at significant speeds whereas Galileo was concerned only with matter moving at normal speeds.
3. Which statement about frames of reference is correct?
   (A) A frame of reference is a system of coordinates in which we make measurements and observations.
   (B) A frame of reference that is accelerating is known as an inertial frame of reference.
   (C) Motion is *not* detectable in a non-inertial frame of reference.
   (D) The principle of relativity holds in all frames of reference.
4. Which of the following is *not* an inertial frame of reference?
   (A) Your classroom.
   (B) The Earth in its orbit around the Sun.
   (C) A roller coaster.
   (D) A car moving at constant speed.
5. Which statement best summarises the principle of relativity?
   (A) Motion in a non-inertial frame of reference is accelerated motion. Motion in an inertial frame of reference is constant motion.
   (B) Motion cannot be detected in an inertial frame of reference without reference to an outside point.
   (C) No experiment can be done in a non-inertial frame of reference to prove that it is moving.
   (D) No experiment can be done in an inertial frame of reference to prove that it is accelerating.
6. Why did Einstein decide that if he was travelling inside a train with no windows at the speed of light, that he must see his reflection in a mirror?
   (A) Because the mirror was at rest relative to him.
   (B) Because he knew that the speed of light is constant regardless of the frame of reference of the observer.
   (C) Because in that situation the light is travelling at twice its speed relative to outside observers.
   (D) Because not seeing his reflection would violate the principle of relativity.
7. What conclusion did Einstein make from his first thought experiment?
   (A) He would see himself in the mirror.
   (B) Both doors of the carriage would open at the same time.
   (C) The back door of the carriage would open first.
   (D) The door that opens first depends on the relative motion of the observer.

Answers

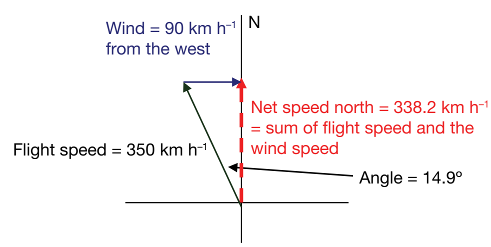
Topic 8 Special Relativity

1 Frames Of Reference and the Principle Of Relativity

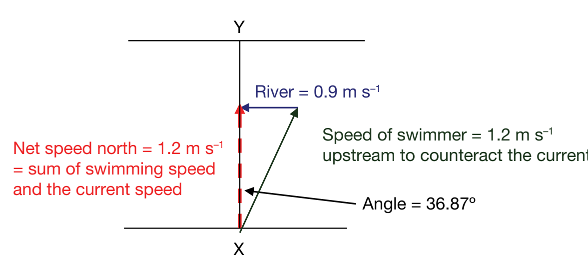
1. The idea of a frame of reference refers to the environment in which you make measurements. Your most common frame of reference is possibly your school laboratory.
2. (a) Inertial.
   (b) Inertial.
   (c) Inertial.
   (d) Non-inertial.
   (e) Non-inertial.
   (f) Non-inertial.
   (g) Inertial.
3. An inertial frame of reference is not accelerating. A non-inertial frame of reference is accelerating.
4. Motion, or lack of motion, cannot be detected within an inertial frame of reference without referring to some object outside the frame. (Often stated as – no experiments can be done within an inertial frame of reference to determine if the frame is at rest or moving with constant velocity.)
5. (a) The spaceship is now accelerating in the opposite direction to the way the mascot is hanging.
   (b) Inertial frame of reference. No inertial forces were acting on the mascot.
   (c) Non-inertial frame of reference. There is an inertial force opposing the acceleration of the spaceship acting on the mascot.
6. Answers will vary, for example: Measurements made without considering the frame of reference in which they are made can be misleading. For example, ancient astronomers considered the Earth to be stationary and that the Sun and Moon (and the rest of the Universe) rotated about it. This misconception guided the thinking of those astronomers for centuries before improved technology enabled later astronomers to discover the true situation.
7. (a) D
   (b) The comet is stationary and you are moving away from Andromeda.
   You are both moving away from Andromeda, but you are moving away much faster than the comet.
8. B
9. C

2 Galilean Transformations

1. A Galilean transformation is one in which normal mathematics can be applied in order to determine the relative motion. It compares motion in different frames of reference using only Newtonian physics and ignores relativistic effects.
2. Galilean transformations hold at low speeds where relativistic effects can be ignored. If objects are moving at significant proportions of the speed of light the relativistic effects must be considered, so a simple Galilean transformation would be invalid.
3. Taking east as positive – subtract the velocity it is relative to:
   (a) $V_x - V_y = 30 - (-25) = 55$ m s^{-1} east
   (b) $V_x - V_z = 30 - 15 = 15$ m s^{-1} east
   (c) $V_y - V_x = (-25) - 30 = -55$ or 55 m s^{-1} west
   (d) $V_y - V_z = (-25) - 15 = -40$ or 40 m s^{-1} west
   (e) $V_z - V_x = 15 - 30 = -15$ or 15 m s^{-1} west
   (f) $V_z - V_y = 15 - (-25) = 40$ m s^{-1} east
4. Velocity of A relative to B = − velocity of B relative to A (i.e. opposite direction)
5. (a) $V_x - V_y = V_x + (-V_y)$;
   $V^2 = 24^2 + 18^2 = 900$; $v = 30$ m s^{-1}
   $\theta = \tan^{-1}\dfrac{18}{24} = 37°$ or E 37° S (or bearing 127°)
   (b) $V^2 = 24^2 + 18^2 = 900$; $v = 30$ m s^{-1}
   $\theta = \tan^{-1}\dfrac{18}{24} = 37°$ or W 37° N (or bearing 307°)
6. Taking south as positive:
   (a) $V_A - V_B = 55 - (-25) = 80$ m s^{-1} south
   (b) $V_B - V_A = -25 - 55 = -80$ or 80 m s^{-1} north
7. (a) A
   (b) The observers are in different inertial frames of reference.
8. (a) Sine rule: $\dfrac{\sin 45°}{100} = \dfrac{\sin\theta}{30}$; $\theta = \sin^{-1}\dfrac{30 \times \sin 45°}{100}$
   = 12.24° or bearing 012°
   (b) Cosine rule: $v^2 = 100^2 + 30^2 - 2 \times 100 \times 30 \times \cos 123°$;
   $v = 119$ km h^{-1}
9. (a) 1.2 m s^{-1} E
   (b) 1.6 m s^{-1} across (north)
   (c) $v^2 = 1.2^2 + 1.6^2$; $v = 2.0$ m s^{-1} at 37° downstream from straight across (bearing 233°)
   $\theta = \tan^{-1}\dfrac{1.2}{1.6} = 37°$
10. (a) (i) $v = 1.75 + 0.45 = 2.2$ m s^{-1} downstream
    (ii) $v = 1.75 - 0.45 = 1.3$ m s^{-1} upstream
    (b) (i) 1.75 m s^{-1} downstream
    (ii) 1.75 m s^{-1} upstream
11. (a) $s = vt = (4.25 - 3.75) \times (5 \times 60) = 150$ m upstream
    (b) $s = (4.25 + 3.75) \times (5 \times 60) = 2400$ m downstream
12. (a) 30 km h^{-1} bearing 045°
    (b) $v^2 = 200^2 + 30^2 - 2 \times 200 \times 30 \times \cos 45°$; $v = 180$ km h^{-1}
    $\dfrac{\sin 45°}{180} = \dfrac{\sin\theta}{30}$; $\theta = \sin^{-1}\dfrac{30 \times \sin 45°}{180}$
    = 6.8° or 180 km h^{-1} bearing 172°
    (c) $v^2 = 200^2 + 30^2 - 2 \times 200 \times 30 \times \cos 135°$; $v = 222$ km h^{-1}
    $\dfrac{\sin 135°}{222} = \dfrac{\sin\theta}{30}$; $\theta = \sin^{-1}\dfrac{30 \times \sin 135°}{222}$
    = 5.5° or 225.2 km h^{-1} bearing 005°
    (d) $\dfrac{\sin 45°}{200} = \dfrac{\sin\theta}{30}$; $\theta = \sin^{-1}\dfrac{30 \times \sin 45°}{200} = 6°$ or bearing 006°
    (e) $\dfrac{\sin 45°}{200} = \dfrac{\sin 129°}{v}$; $v = 220$ km h^{-1}
13. (a) $\theta = \sin^{-1}\dfrac{5}{15} = 19.5°$ or bearing 342°
    (b) 15 m s^{-1}
    (c) $v^2 = 15^2 - 5^2$; $v = 14.14$ m s^{-1}
    (d) $t = \dfrac{s}{v} = \dfrac{450}{14.14} = 31.8$ s
14. Vector sketch for the information (not to scale).



    (a) $\theta = \sin^{-1}\dfrac{90}{350} = 14.9°$; Heading = N 14.9° W or bearing 345.1°
    (b) $v^2 = 350^2 - 90^2$; $v = 338.2$; Speed relative to ground = 338.2 km h^{-1}
15. Vector sketch for the information (not to scale).



    (a) 0.9 m s^{-1} west
    (b) $\theta = \tan^{-1}\dfrac{0.9}{1.2}$
    = 36.87°; 1.5 m s^{-1} at 36.87° upstream from straight across the water.
    (c) $v^2 = 1.5^2 - 0.9^2$; $v = 1.2$ m s^{-1} from X to Y