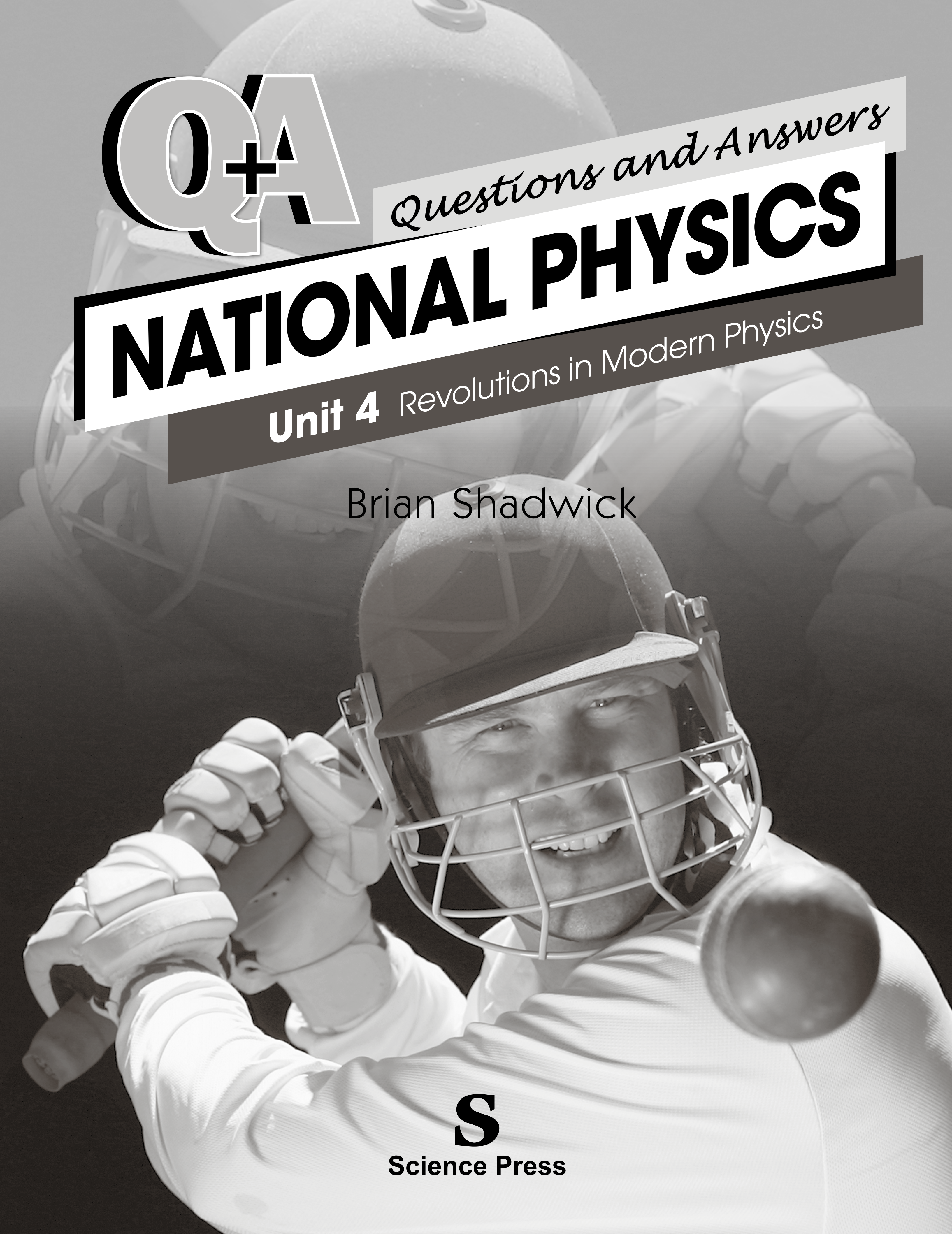
Q+A

Questions and Answers

NATIONAL PHYSICS

Unit 4 Revolutions in Modern Physics

Brian Shadwick



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Contents

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.

Q+A
Questions and Answers

Special Relativity

SET 1 Frames of Reference

1. (a) What is a frame of reference?
(b) Identify the two common types of frames of reference used in the study of motion.
(c) Describe the difference between these two types of frames of reference.

2. (a) What is the principle of relativity?
(b) Outline the importance of the principle of relativity with reference to both types of frames of reference.

3. (a) There are three frames of reference that we classify as being inertial frames. What are they?
(b) According to your answer to (a), the Earth would be considered as an inertial frame of reference (and for most simple applications we do accept it as such). In fact, technically it is not. Explain why.

4. Classify each of the following as an inertial or non-inertial frame of reference and explain your choice.
(a) The Earth.
(b) Your bedroom.
(c) A helicopter in constant, level flight.
(d) A roller coaster.
(e) A car turning a corner.
(f) A ‘wheel of terror’ at a fun park.
(g) A satellite in a geostationary orbit.

5. A passenger in a train took off his tie and hung it from a hook on the luggage rack above him. Throughout the journey he noticed sometimes:
(i) The tie hung straight down.
(ii) The the tie seemed to lean towards the windows of the train.
(iii) The the tie seemed to lean towards the centre aisle.
(iv) The the tie seemed to lean backwards.
(v) The tie seemed to lean forwards in the same direction the train was moving.
Assuming the windows of the train are on the passenger’s left, then by writing your answers in an appropriate table:
(a) Account for each of these observations in terms of the motion of the train.
(b) Identify the frame of reference for each observation, justifying each answer.

6. You regain consciousness some time after an asteroid hits your spaceship. You are unaware of any movement of the craft. You wonder if you are still on course and moving towards Andromeda galaxy. A comet shoots past you, seemingly parallel to your path and moving straight ahead.
(a) 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 the relative motion that could lead to the same observation.

7. Which of the following is a correct statement?
(A) A net force cannot exist in an inertial frame of reference.
(B) A net force cannot exist inside a non-inertial frame of reference.
(C) An inertial frame of reference can be detected by an observer inside the system.
(D) A non-inertial frame of reference cannot be detected by an observer inside the system.

SET 2 Galilean Transformations

1. (a) What is a Galilean transformation?

(b) When do we use Galilean transformations?

(c) When can't we use Galilean transformations?

(d) What do we use when we cannot use Galilean transformations?

2. Object X is moving north at 45 m s^{-1}. Object Y is moving south at 60 m s^{-1}. Object Z is moving north at 25 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.

3. Object X is moving north at 45 m s^{-1}. Object Y is moving east at 60 m s^{-1}. Object Z is moving south at 25 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 Questions 2 and 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. Michael, 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 0.8 m s^{-1} east.

Calculate the velocity of:

(a) The water relative to the bank.

(b) Michael relative to the water.

(c) Michael relative to the bank.

(d) Imagine that Michael has to end up at Y rather than being carried downstream by the river. In what direction would he need to swim in order to accomplish this?

(e) What would be Michael's speed relative to X in situation (d)?

6. A rowing team can row a boat at 2.5 m s^{-1} in still water. They row on a river flowing at 0.5 m s^{-1}.

(a) Calculate the velocity of the boat relative to the banks of the river if the team rows:

(i) With the flow.

(ii) Against the flow.

(b) Calculate the velocity of the boat relative to the water if the team rows:

(i) With the flow.

(ii) Against the flow.

7. A plane is flying north at 300 km h^{-1} when it hits an 80 km h^{-1} wind from the south-east. 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.

8. A boat, capable of travelling at 3.5 m s^{-1} in still water sets out to travel from X to Y a distance of 800 m due north. A current flows from the west at 0.7 m s^{-1}. Calculate:

(a) The direction the boat takes to move directly from X to Y.

(b) Its speed relative to the water.

(c) Its speed relative to the ground.

(d) How long it will take to make the journey.

SET 3 Constancy of the Speed of Light

1. (a) Describe what is meant by a frame of reference.

(b) Give an example of a frame of reference that is common for you.

2. Using the example of the ideas of ancient astronomers, discuss why it is important for us to consider our frame of reference when we make measurements.

3. (a) Distinguish between inertial and non-inertial frames of reference, and give an example of each.

(b) How would we know if we were in an inertial or a non-inertial frame of reference?

(c) You have been kidnapped and wake to find yourself in a totally closed cabin in a spaceship. How can you work out if the spaceship is moving or stationary? Explain the physics behind your answer.

4. (a) What is inertia?

(b) Teachers often talk about inertial forces. Inertial forces are ‘fictitious’ forces. That is, they do not actually exist. Explain this statement.

(c) In which frames of reference do we notice these inertial forces acting, and in which frames do inertial forces not act? Explain why.

(d) Outline the connection between the feeling astronauts in orbit have of being ‘weightless’ and frames of reference. Explain why.

5. You regain consciousness some time after a meteor hits 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 another ship shoots past you, seemingly parallel to your path and moving straight ahead.

Give five interpretations of the movements of your spaceship and/or the other spaceship which would explain this observation.

6. An astronaut tied her mascot to a string and hung it from the ceiling. One day she 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 when the mascot hangs at an angle. Justify your answer.

7. (a) Describe the thought experiment Einstein carried out which led to his proposal that the speed of light was constant.

(b) What were the two possible outcomes for this thought experiment?

(c) What conclusion did Einstein make for this experiment?

(d) What was Einstein’s reasoning for this conclusion?

8. (a) What are the advantages of thought experiments?

(b) What are the limitations of thought experiments?

(c) Why was Einstein’s work on special relativity derived from thought experiments rather than from real experiments?

(d) Discuss whether or not thought experiments have a place in the methodology of scientific discovery.

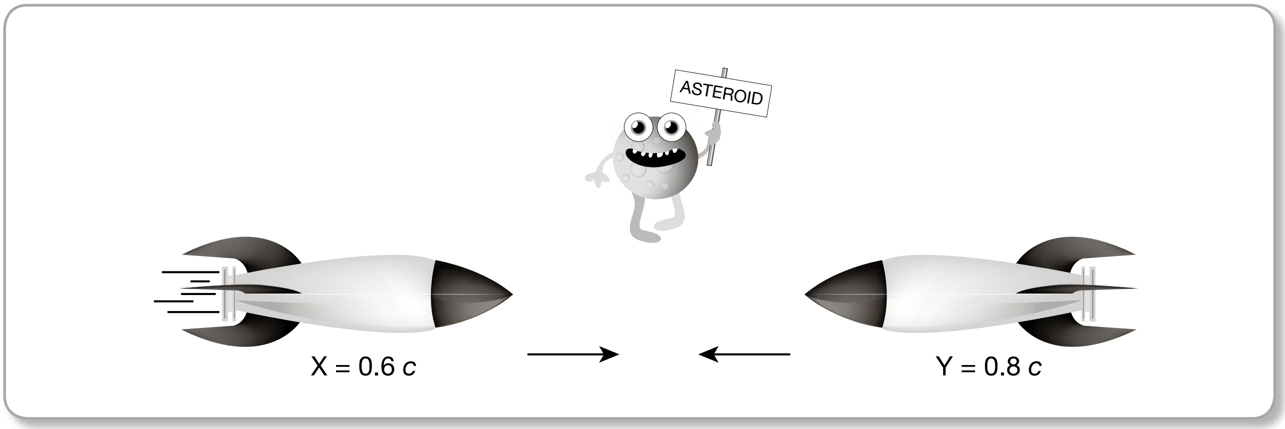
9. (a) Recall the two postulates of Einstein’s theory of special relativity.

(b) In what way did these postulates change the scientific thinking in the early 1900s?

10. (a) According to Newton's physics, what is the maximum speed for any object, including light?

(b) According to Einstein's physics, what is the maximum speed for any object, including light?

11. Two spaceships are travelling through space towards each other. X is travelling at 0.6 c while Y is travelling at 0.8 c as shown in the diagram. Asteroid man watches them from far away.



X sends a radio message to Y.

(a) At what speed does the radio message travel to Y according to the observer on the asteroid?

(b) At what speed does the radio message reach Y?

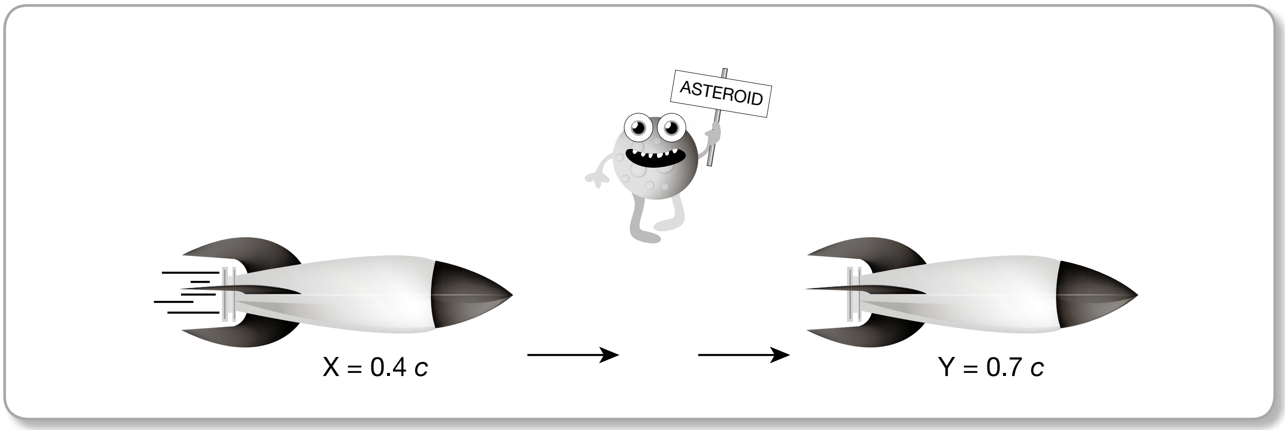
(c) At what speed does the radio message travel away from X?

(d) At what speed does the radio message travel to Y according to the pilot of X?

(e) At what speed does the radio message travel to Y according to the pilot of Y?

(f) Asteroid man also picks up the radio signal. At what speed does the signal reach him?

12. Two spaceships are travelling through space. X is travelling at 0.4 c while Y is travelling at 0.7 c in the same direction as shown in the diagram. Asteroid man watches them from far away.



Y sends a radio message to X.

(a) At what speed does the radio message travel to X according to the observer on the asteroid?

(b) At what speed does the radio message reach X?

(c) At what speed does the radio message travel away from Y?

(d) At what speed does the radio message travel to X according to the pilot of X?

(e) At what speed does the radio message travel to X according to the pilot of Y?

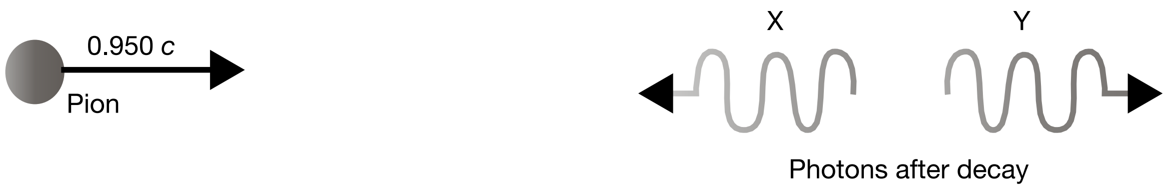
(f) Asteroid man also picks up the radio signal. At what speed does the signal reach him?

SET 4 Galilean and Relativistic Transformations

1. The way we analyse motion using Newtonian concepts is referred to as making a Galilean transformation. Describe what mathematics we use to make Galilean transformations.

2. In what situations do Galilean transformations not hold? Explain your answer.

3. A pion is an unstable particle that decays into two photons. A particular pion, travelling at 0.950 c with respect to an observer at rest, decays into two photons, X and Y travelling in opposite directions as shown in the diagram.



The speed of both photons as measured by the observer at rest with respect to the pion is c.

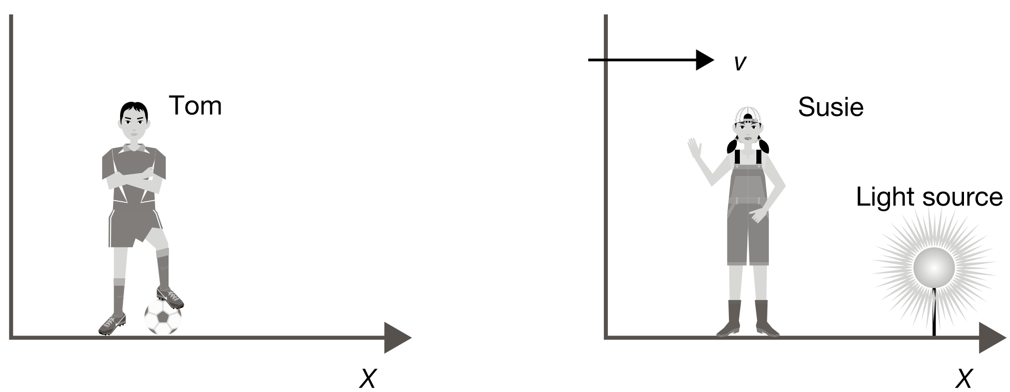
(a) Calculate the velocity of photon X with respect to the observer using Galilean kinematics.

(b) Calculate the velocity of photon Y with respect to the observer using Galilean kinematics.

(c) What will be the velocity of photon X with respect to the observer according to Einstein's postulates?

(d) What will be the velocity of photon Y with respect to the observer according to Einstein's postulates?

4. In the diagram below, Tom's reference frame is at rest and Susie's is moving away from him with constant speed v in the x-direction.



Susie carries out an experiment to measure the speed of light from a source which is at rest in her reference frame. The value of the speed that she obtains is c.

(a) Apply a Galilean transformation to find the value that Tom would obtain for the speed of light from Susie's source.

(b) State the value that Tom would be expected to obtain for the speed of light from Susie's source based on Einstein's postulates.

5. Einstein's postulates also include the concept that nothing can travel faster than the speed of light. This includes the relative velocity of high speed objects travelling towards each other.

When objects travelling at relativistic speeds approach each other, a simple Galilean transformation does not work either. Relativistic mathematics provides us with the following formula.

For objects approaching each other:

$$\text{Relative velocity} = \frac{(v_1 + v_2)}{\left(1 + \frac{v_1 v_2}{c^2}\right)}$$

(a) Two spaceships approach each other, both travelling at 0.75 c. According to Galilean transformations, what is the speed of each spaceship relative to the other?

(b) What are their relative speeds according to relativistic mathematics?

(c) If they approach each other, both travelling at the speed of light, what will be their relative speeds according to Galilean transformations?

(d) What are their relative speeds according to relativistic mathematics?

6. Two spaceships approach each other at 0.8 c. What is their speed relative to each other:

(a) According to Galilean transformation?

(b) According to relativistic mathematics?

7. When the two objects (including radio messages) are travelling at relativistic speeds in the same direction, the simple Galilean transformation does not work either. The relativistic mathematics formula in this situation is as follows.

For objects travelling in the same direction:

$$\text{Relative velocity} = \frac{(v_1 - v_2)}{\left(1 - \frac{v_1 v_2}{c^2}\right)}$$

A spaceship travelling at 0.6 c transmits a message to another spaceship which is moving towards it at 0.4 c.

(a) Determine the speed of the message relative to the spaceship.

(b) Calculate the speed at which the second ship receives the message.

(c) What do your answers help prove about the speed of electromagnetic radiation?

8. Ship X is travelling through space at 0.4 c. Ship Y is travelling in the same direction as X at 0.7 c.

(a) Determine the speed of Y relative to X.

(b) Determine the speed of X relative to Y.

9. Two protons in the Hadron Collider approach each other at 0.95 c. What will be the combined speed at which they collide with each other according to:

(a) Newton?

(b) Einstein?

10. Spaceship X, travelling at 0.8 c, sends a radio message to spaceship Y, travelling in the same direction at 0.5 c, and to spaceship Z, travelling in the opposite direction at 0.2 c.

(a) Calculate the speed of spaceship X relative to spaceship Y.

(b) Calculate the speed of spaceship Y relative to spaceship X.

(c) Calculate the speed of spaceship X relative to spaceship Z.

(d) Calculate the speed of spaceship Z relative to spaceship X.

(e) Calculate the speed of spaceship Y relative to spaceship Z.

(f) Calculate the speed of spaceship Z relative to spaceship Y.

(g) Calculate the speed of the radio message relative to spaceship X.

(h) Calculate the speed of the radio message relative to spaceship Y.

(i) Calculate the speed of the radio message relative to spaceship Z.

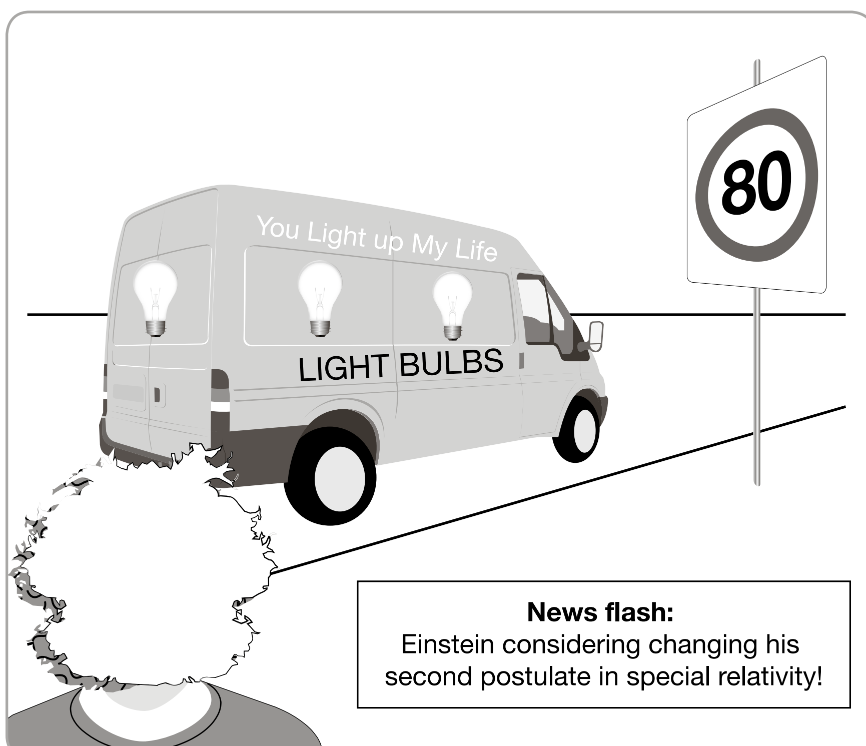
SET 5 Consequences of Einstein's Postulates

1. State the two postulates that Einstein made as a result of his developing his theory of special relativity.

2. (a) What are 'standard' units of measure?
(b) Why do we need standards of measure?
(c) What does the phrase 'SI units' refer to?
(d) Why do we use these?
(e) The standards for the SI units have changed over the years. Suggest why these changes were made.
(f) The last changes to SI units were made following Einstein's postulate on the constancy of the speed of light. Why were these changes made?
(g) In what way were the standards changed?

3. (a) What is a frame of reference?
(b) What is meant by a 'rest frame'?
(c) Give an example of a rest frame.
(d) What was the importance of a rest frame for Newtonian physics?
(e) What is an 'absolute rest frame'?
(f) Explain why the rest frame you gave as an example in (c) above is not an absolute rest frame.
(g) A consequence of Einstein's postulate is that Newton's assumption of an absolute rest frame is not valid. Explain why.

4. In 1905, Einstein wrote in *Annalen der Physik,* that '… light is always propagated in empty space with a definite velocity *c* which is independent of the state of [relative] motion of the emitting body … The introduction of a 'luminiferous ether' will be superfluous in as much as the view here to be developed will not require an 'absolutely stationary space' provided with special properties.'



(a) What consequence of the constancy of the speed of light is Einstein referring to in this statement?
(b) Explain why Einstein made this statement. (Note that there is no evidence anywhere to show that Einstein knew about the Michelson-Morley experiment.)

5. List four main consequences for science as a result of Einstein's postulate of the constancy of the speed of light.

Q+A Questions and Answers

ANSWERS

Set 1 Frames of Reference

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

(b) Inertial and non-inertial frames of reference.

(c) Inertial frames of reference are frames which have zero acceleration, non-inertial frames of reference are accelerating and experience inertial forces.

2. (a) The principle of relativity states that the laws of motion hold in all frames of reference, but in an inertial frame of reference no observation or experiment can be made *inside* the frame to determine whether or not the frame is at rest or moving with constant velocity. Reference must be made to some object outside the frame of reference to determine this.

(b) Because the motion of an inertial frame cannot be detected from within the frame, the principle of relativity can be used to distinguish between inertial and non-inertial frames of reference.

3. (a) Stationary frames.

Frames moving with constant velocity.

Frames in constant motion, circular orbits.

(b) The complication here is that the Earth is also spinning on its axis, and this motion can be detected without making observations outside the frame of reference of the Earth (see Foucault pendulum). For this reason, it is technically not an inertial frame, but the acceleration due to this rotation is essentially negligible for most simple considerations, and can therefore be ignored.

4. (a) Inertial frame of reference.

(b) Inertial frame of reference.

(c) Inertial frame of reference.

(d) Non-inertial frame of reference.

(e) Non-inertial frame of reference.

(f) Non-inertial frame of reference.

(g) Inertial frame of reference.

5.

	Explanation	Frame of reference
(i)	Train is either stationary or moving with constant velocity	Inertial frame of reference
(ii)	Train is turning to the right	Non-inertial frame of reference
(iii)	Train is turning to the left	Non-inertial frame of reference
(iv)	Train is accelerating forwards	Non-inertial frame of reference
(v)	Train is braking	Non-inertial frame of reference

6. (a) D

(b) See alternatives A, B and C in Question 6(a).

7. C

Set 2 Galilean Transformations

1. (a) 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.

(b) When we want to compare motion in different frames of reference using only Newtonian physics.

(c) Galilean transformations cannot be used when relativistic effects have to be considered, that is, when objects are travelling at a significant proportion of the speed of light.

(d) We use Einstein's relativistic mathematics.

2. (a) 105 m s^{-1} north

(b) 20 m s^{-1} north

(c) 105 m s^{-1} south

(d) 85 m s^{-1} south

(e) 20 m s^{-1} north

(f) 85 m s^{-1} north

3. (a) 75 m s^{-1} bearing 307°

(b) 70 m s^{-1} north

(c) 75 m s^{-1} bearing 127°

(d) 65 m s^{-1} bearing 067°

(e) 70 m s^{-1} south

(f) 65 m s^{-1} bearing 247°

4. Velocity of A relative to B = –velocity of B relative to A.

5. (a) 0.8 m s^{-1} east
(b) 1.6 m s^{-1} across (at 90° to the river current)
(c) 1.8 m s^{-1}
(d) 30° upstream to straight across
(e) 1.39 m s^{-1}

6. (a) (i) 3.0 m s^{-1} downstream
(ii) 2.0 m s^{-1} upstream
(b) (i) 2.5 m s^{-1} downstream
(ii) 2.5 m s^{-1} upstream

7. (a) 80 km h^{-1} north-west (Note wind directions are always stated as the direction from which they come.)
(b) 250 km h^{-1} bearing 193°
(c) 361 km h^{-1} bearing 013°
(d) Bearing 349.1°
(e) 330 km h^{-1}

8. (a) 11.5° upstream relative to straight across
(b) 3.5 m s^{-1}
(c) 3.43 m s^{-1}
(d) 233.3 s = 3.9 minutes

Set 3 Constancy of the Speed of Light

1. (a) The idea of a frame of reference refers to the environment in which you make measurements.
(b) Your most common frame of reference would be your school laboratory, or your home, or the school playground.

2. 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 the Moon (and the rest of the Universe) revolved about it. This misconception guided the thinking of astronomers for centuries before improved technology enabled later astronomers to discover the true situation.

3. (a) An inertial frame of reference is one which is either stationary or moving with constant velocity, or one which is in a stable orbit around a primary. For example, the Earth in orbit around the Sun is an inertial frame of reference.
A non-inertial frame of reference is one which is accelerating. For example, a car turning a corner, or a plane which is accelerating down the runway.
(b) Without referring to some object known to be stationary outside your frame, you cannot find this out.
(c) This relates to the principle of relativity, which in part states that we cannot determine whether or not an inertial frame of reference is moving at constant speed or is stationary, without referring to a stationary reference object outside the frame of reference. For example, in this case, we may need to refer to a nearby planet (which of course we cannot see from inside the enclosed cabin).

4. (a) Inertia is the property any body has which resists any attempt to change its state of uniform rest or motion.
(b) Whenever an object accelerates, its inertia acts to try to keep it in the same place. We experience this when a plane accelerates down a runway. We 'feel' a force pushing us backwards into our seats. There is no such force. What we actually feel is the reaction force our bodies apply to the back of the seat which is accelerating us forwards.
(c) Inertial forces are felt in non-inertial frames of reference. Because they are accelerating, objects within them will have inertia and therefore be subject to the feeling that a force is acting on them in the opposite direction to the acceleration.
(d) Inertia does not act in inertial frames of reference because no acceleration is involved. They have a centripetal acceleration provided by the value of 'g' at their altitude – a substantial 7 or 8 m s^{-2}.

5. Both you and the other ship are travelling towards Andromeda, but the other ship is moving faster than you.
You are stationary and the ship is moving past you towards Andromeda.
You are moving backwards and the ship is moving towards Andromeda.
The ship 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 other ship.

6. (a) Craft was no longer an inertial frame of reference. Craft was accelerating in the opposite direction to the angle of hang.
(b) Inertial frame of reference. If the craft was accelerating, inertial forces would be noticeable (the mascot would not hang vertically down). (*Note:* We cannot determine by any experiment if the frame of reference is stationary or moving with constant velocity without referring to some point outside the frame of reference.)
(c) Non-inertial – accelerated motion is detectable because of the inertial forces acting on the mascot and causing it to hang at an angle.

7. (a) Einstein considered himself to be in a train moving at the speed of light, holding a mirror up in front of his face and wondered whether or not he would see his reflection.
(b) He would either see his reflection or he would not.
(c) He concluded that he would see his reflection.
(d) His reasoning was based on his belief that the principle of relativity could not be violated. He reasoned that if he could not see himself, then this would be an experiment that would prove that the train, an inertial frame of reference, was moving with constant velocity faster the speed of light. Because this would violate the principle of relativity, he concluded that he must see his reflection.

8. (a) Thought experiment are not bound by any limitations in technology or conventions of ideas. They can roam wherever they might.

(b) By their nature, thought experiments along the lines of Einstein's could not be tested by actual experiment at that time, so convincing other scientists that the experiments and conclusions are valid presents a problem.

(c) The technology to carry out actual experiments along the lines of his thought experiments did not exist (until some 50 years later).

(d) They definitely have a place. They stimulate other scientists to either believe and therefore work to gain evidence or improve their conclusions, or to disbelieve and work to disprove them. Both courses of action often result in the development of further new ideas and advances in scientific thinking.

9. (a) 1. The laws of physics are the same for all inertial observers. (Note that this is sometimes expressed as: All motion is relative and the principle of relativity holds in all situations.)

2. All inertial observers will measure the same value for the speed of light irrespective of their velocity relative to the source. (Note that this is often expressed as: The speed of light is constant regardless of the observer's frame of reference.)

(b) The ideas expressed in the first postulate had been around since the time of Newton, and simply reiterated that idea. It did not cause any change in scientific thinking. However, the second postulate – the consistency of the speed of light was to cause major changes. It redefined the standards of measurement and led to the development of special relativity. It also led to the discarding of the aether model for the transmission of light.

10. (a) Infinite.

(b) *c*

11. (a) *c*

(b) *c*

(c) *c*

(d) *c*

(e) *c*

(f) *c*

12. (a) *c*

(b) *c*

(c) *c*

(d) *c*

(e) *c*

(f) *c*

Set 4 Galilean and Relativistic Transformations

1. A Gallilean 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 then relativistic effects must be considered, so a simple Galilean transformation would be invalid.

3. (a) Galilean kinematics indicates that the speed of Y relative to observer is = original speed of pion + speed of Y after decay = 1.95 *c.*

(b) Galilean kinematics indicates that the speed of X relative to observer is = original speed of pion – speed of X after decay (it is moving in the opposite direction) = 0.05 *c.*

(c) *c*

(d) *c*

4. (a) $c - v$

(b) *c*

5. (a) 1.5 *c*

(b) 0.96 *c*

(c) 2 *c*

(d) *c*

6. (a) 1.6 *c*

(b) 0.976 *c*

7. (a) From $v = \dfrac{(u-v)}{\left(1-\dfrac{uv}{c^2}\right)} = \dfrac{(1-0.6)}{\left(1-\dfrac{1\times 0.6}{1^2}\right)} = \dfrac{0.4}{0.4} = 1 = c$

(b) From $v = \dfrac{(u+v)}{\left(1+\dfrac{uv}{c^2}\right)} = \dfrac{(1+0.4)}{\left(1+\dfrac{1\times 0.4}{1^2}\right)} = \dfrac{1.4}{1.4} = 1 = c$

(c) The speed of electromagnetic radiation is constant regardless of the frame of reference of the observer.

8. (a) From $v = \dfrac{(u-v)}{\left(1-\dfrac{uv}{c^2}\right)} = \dfrac{(0.7-0.4)}{\left(1-\dfrac{0.7\times 0.4}{1^2}\right)} = 0.42\ c$

(b) From (a), speed of X relative to Y will 0.42 *c* in the opposite direction.

9. (a) 1.9 *c*

(b) 0.999 *c*

10. (a) 0.5 *c* towards Y

(b) 0.5 *c* towards X

(c) 0.86 *c* towards Z

(d) 0.86 *c* towards X

(e) 0.64 *c* towards Z

(f) 0.64 *c* towards Y

(g) *c*

(h) *c*

(i) *c*

Set 5 Consequences of Einstein's Postulates

1. The speed of light in a vacuum is an absolute constant.

All inertial frames are equivalent.

2. (a) Standard units of measure are measures that are very accurately known.

(b) A set of standards is needed so that everyone reports measurements the same way. This means the reports will be understood throughout the world.

(c) Standard International Units or Système Internationale or International System of Units.

(d) So that people throughout the world make measurements and report measurements in the same 'language'. It makes measurements throughout the world understood by everyone.

(e) The standards changed as technology improved and more accurate ways were developed to define the standards.

(f) Standards used to be based on the measurement of length, mass and time (the three fundamental quantities on which all other units are based). With special relativity, these could not be considered constant as they all depended on the relative velocity of the person making the measurement.

(g) The standards were changed to be defined using the speed of light, the only constant quantity in the Universe, as the basis for definition.

3. (a) A frame of reference is the environment in which we make measurements.

(b) A rest frame is a frame of reference which is stationary relative to the object we are considering.

(c) The room you are sitting in at the moment is your current rest frame. It is at rest relative to you.

(d) In Newton's physics measurements are compared on the basis that they can all be referred to a frame of reference that is at rest. This is how the motion of individual objects is measured and stated (for example, relative to the ground – assumed to be at rest).

(e) An absolute rest frame is a frame of reference which is at absolute rest. It is stationary with respect to everything in the Universe.

(f) While the room is at rest relative to you, it is moving with the rotation of the Earth on its axis, and with the Earth's orbital motion around the Sun, and with the rotating motion of the Milky Way galaxy, and with the translational motion of the galaxy as it moves with the expansion of the Universe (same answer will apply regardless of the frame you choose).

(g) This is not a simple concept. According to Einstein, space and time cannot be separated, but exist jointly as spacetime.
In spacetime there is no absolute rest frame because everything in the Universe is moving relative to all other things in the Universe. One frame of reference may be at rest relative to another frame, but it will always be moving relative to other frames.

4. (a) Einstein is referring to the fact that because of the consistency of the speed of light, there is not need to invent an aether as a medium to propagate light.

(b) If light was carried by a stationary medium, then the velocity of light would not be constant to all observers, because the observer's motion relative to the aether would affect the relative velocity of the medium to the observer, and therefore the velocity of light relative to the observer.

5. Any four of:

(a) Mass, length and time can no longer be considered to be fundamental quantities, they must be considered as relative quantities which depend on the relative motion of the observer, or stated another way:

- Time measured by observers in different frames of reference may not be the same (time dilation).
- Length measured by observers in different frames of reference may not be the same (length contraction).
- Mass measured by observers in different frames of reference may not be the same (mass dilation).

(b) Events considered as occurring at the same time in one frame of reference, may not be considered to be occurring at the same time in a different frame of reference.

(c) Relative velocities for objects moving at relativistic speeds cannot be determined by simple Galilean transformations.

(d) Light, being constant speed, is not carried by an aether, so there is no need to propose that an aether exists.

(e) Space and time can not be considered as independent quantities. Rather we need to consider a new concept, that of spacetime to define an object's position in the Universe (this idea is not covered in this course).