Maastricht University

University College Maastricht

SCI2038
Physics
Period 4 2017/8

Contents

Introduction

Physics is the science of measuring the natural world, as a result, physicists have developed a series of properties and laws of the material world, from the composition of atomic nuclei to the evolution of distant stars. The course describes some of the general laws of nature, valid in the whole Universe, and how such laws could be extracted from the results of carefully planned experiments. Aspects to be considered will be:

- Thermodynamics, including the four laws of thermodynamics, PV diagrams and applications of them
- Momentum, Energy and Work – topics which define how a system moves, and how objects react during (Newtonian) collisions
- Einstein's Theory of Relativity – the modification of Newtonian equations to include an accurate description at high velocity
- Astronomy, Cosmology and Astrophysics – the science of understanding the cosmos and our place in it.

Course Coordinator

Name	Department	Telephone	Location	Email
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Schedule

The course lasts for 8 weeks. In week 2 we take a break for carnival. Each week consists of 2 hours of lectures and 4 hours of tutorial. In week 8 we will have the final exam.

The exact timetable is **subject to change**; please check student portal & myTimetable regularly for the exact place and time of the tutorials and lectures.

Topic schedule:

Week	Week Commencing	Topic
1	5th February	Introduction to Physics Thermodynamics I
2	12th February	Carnival
3	19th February	Thermodynamics II Errors in Physics
4	26th February	Collisions
5	5th March	Energy and Work
6	12th March	Einstein's Theory of Relativity
7	19th March	Astronomy and Astrophysics
8	26th March	Final Exam

Course Objectives

- To use the tools that participants have developed in SCI2018 in a physics environment. This means we will take a journey through a variety of topics of classical and modern physics. The aim is to prepare participants for further studies in the sciences concentration or for admission into future programmes.
- We will review and expand on high school physics as well as observations of the natural world explore the material world in a quantitative manner.

Learning Objects (by topic)

Physics (in general)

- **Identify** the usefulness and **experiment** with thought-experiments in physics
- **Explain** the impact errors have on physical models and calculations

Thermodynamics

- **Define** heat and energy
- **Explain** the 0^{th} and 1^{st} laws of thermodynamics

- **Interpret** P-V diagrams and **understand** what they represent
- **Investigate** typical applications of thermodynamics
- **Give examples** of entropic increase in the Universe
- **Examine** and **analyse** how heat engines and refrigerators work

Mechanics

- **Interpret** numerical and graphical representations of these bodies and **deduce** how they move and the forces acting on them
- **Apply** knowledge of calculus to descriptions of bodies in motion
- **Solve problems** relating to colliding bodies

Theory of Relativity

- **Define** the principles of Relativity
- **Interpret** Space-Time diagrams in Relativity
- **Solve problems** in Relativity, in particular the key paradoxes which arise as a result of the principles of Relativity.
- **Apply** knowledge to resolving Relativity problems.

Astronomy & Astrophysics

- **Identify** the key problems in Astronomy and Astrophysics
- **Describe** methodologies for making measurements on a cosmological scale
- **Interpret** cosmological data and **apply** your conclusions to understanding large-scale phenomena.
- **Relate** telescope design and construction to resolution ability and **deduce** which types of telescopes are best for different applications.

Assessment

There are two possible schemes of assessment during this course:-

- 40% of the grade is attributed to a written paper due in week 7
- 60% of the grade is attributed to the final examination in week 8

The examination will consist of a combination of mathematical problems and open, conceptual questions. The final examination will address material from the entire course. The examination will be closed book. The paper will address material from the topic of physics, explicitly *not* taught in this course. See "**coursework assignment**" below.

Reminder:- In order to be eligible for a resit – you **must** give the course coordinator the opportunity to assess you at each assessment you choose to complete.

Resit

An opportunity to resit is available at the end of period 6:- this will be a resit of the lowest scoring assessment component **only** – the grade for the resit replaces the lowest scoring assessment component only – and not the other components of assessment.

Attendance

Participants must have attended at least 85% of the tutorial group meetings to be allowed to take the final test of the course. This course consists of a total of 11 tutorial group meetings; therefore students must attend at least 9 meetings to be considered to have met the compulsory attendance requirement. Students who arrive more than five minutes late to a meeting or who through lack of preparation or participation are not contributing to the tutorial group may be marked as absent.

Additional Assignment

Students who failed to meet the attendance requirement of the tutorial group meetings – but not more than 30% of the group meetings are eligible for an additional assignment. To apply for this, you need to complete the 'Additional assignment because of insufficient attendance' form – available from the UCM intranet within 10 working days of the completion of the course. The course is considered to be completed on the date of the final examination. The reasons for absence must be justified with a valid reason. Should the course coordinator agree that the reasons are valid– an additional assignment will be set – this will reflect the quantity and content of the group meetings that were missed.

Course Books

The **required** reading for this course is a general physics book, very broad, not particularly mathematical:

University Physics with Modern Physics, H.D. Young & R. A. Freedman, Pearson Education (US), 13th International edition, May 2011

A copy is available as in "reference list" available on ELEUM, but a *physical* copy is extremely useful for you to study with. An alternative is to obtain a relatively cheap (2^{nd} hand) copy available in Maastricht or from for example Amazon.

The Feynman lectures in Physics is also freely available online. A link will be provided on ELEUM. This is at a higher level, but is an extremely comprehensive text.

Coursework Assignment

The coursework for this module is essentially a free choice for you – the participant. I intend this to be an *opportunity* for you to demonstrate knowledge about the area of physics without being placed in a formal examination situation. It should be a piece of work you're proud and not something which is rushed together in the last 24 hours before the deadline. The written work should be between 4 and 8 pages; with sufficient detail provided and without too much superfluous text.

You can select a target audience, but this should be clear from the text or otherwise stated separately. For example you can write a magazine style article for the general public, something for your UCM colleagues, or a piece of work for other participants following this course.

The coursework topic is a semi-free-choice. It **must** be from a topic in physics that we have *not* discussed or addressed in a lecture or a PBL session. I would recommend selecting something that is *interesting* to you – since this motivates you to work on it more than something that is boring. It should also be a topic of relative novelty; for example, you could choose to look at:-

- Black holes (their nature, formation, Hawking Radiation etc.)
- Quantum mechanics and wave/particle duality
- Electromagnetism, magnetic levitation (MAGLEV), wireless charging, etc.
- Modern Physics Experiments, such as Super-K or particle accelerators such as the LHC
- String Theory, Supersymmetry or some other theories of the Universe we haven't yet proven
- Future physics, such as teleportation, quantum computation, fusion power
- Anything which is related to physics and captures your imagination

You should select a topic and discuss it with me during the **tutorial timeslot** on Friday 9th March 2018 (Week 5 of the course) (the tutorial will be cancelled at this time; you can instead come to my office during this two hour time slot).

This work must be focussed, thorough, original and individual. It is <u>your</u> work and your work alone. Do not copy whole sentences from your sources – any sources that you do use need to be referenced correctly.

UCM offers an extremely good writing style guide for written work; please use this in completing this assignment. It is available on the UCM intranet.

In completing this work, you must:

- obey academic best practice
    - fully reference the work in a suitable style [One of the scientific citation systems – such as used in AIP]
    - avoid plagiarism (intentional or accidental) in line with UCM/UM policies
- submit the work to SafeAssign on ELEUM **before Friday 23rd March 2018 at midday (12:00pm**)
    - written work submitted by email, to my personal pigeon hole or anywhere else will **not** be accepted
    - late submission incurs a 1 grade point penalty per 24 hour period that it is late, no work accepted more than 5 working days late.

This work makes up 40% of the final grade for SCI2038.

Educational Format

The teaching format for tutorials will be Problem-Based Learning (PBL), which is based on the principle that being confronted with a problem and trying to solve it is an efficient way to acquire knowledge. Physicists are well known for their problem solving abilities and this skill can also serve you well during your education. Every session starts with the appointment of a chairperson and a secretary. The latter keeps a record of the meeting results, learning goals, etc. The chairperson sees that the following “seven steps” are followed:

1) After reading the task, verify that every group member understands what is asked. If necessary, clarify unknown definitions or technical terms.

2) Take some time to agree on the central issue(s) considered of importance in this specific case, and define the problem involved.

3) Use (reactivated) group knowledge to analyse the problems and suggest solutions. Use your common sense brainstorm in this phase.

4) Use the secretary’s record to make an inventory of what you know and have solved. Define lacking knowledge and the remaining aspects to be studied.

5) Formulate the learning goals to be studied. Generally, do not divide these goals between group members, to avoid mini-lectures instead of discussion in the next group meeting.

6) Group members now start their individual study, guided by the learning goals. Keep in mind that you will have to explain your results to other group members. Use a selection of high quality sources to determine the correct answer.

7) Synthesise the obtained information during the next meeting and formulate the final group answer to the problem.

Each week of this course is roughly devoted to one of the main subjects of physics, and starts with a lecture covering some of the content of that subject. This is followed by two group meetings. The first session may start with a short review of the lecture. Following this there will be a post-discussion and a pre-discussion in each tutorial.

In addition, some “individual exercises” will be issued for completion outside of the tutorial will allow you to tackle the more technical problems that need individual concentration and will probably not benefit from treatment in the group. They can better be solved at home. Students with questions about or difficulties with these exercises/problems can present them in the tutorial meetings or individually with the course coordinator.

Tasks

There are 10 tasks which will be completed during this course, the schedule will be as follows:

Week	Week Commencing	Tutorial 1	Tutorial 2
1	5th February	Code of Conduct & Intro. Pre-discuss: Thought-Experiments in Physics	Post-Discuss: Thought-Experiments in Physics Pre-Discuss: Mpemba Effect
2	12th February	Carnival	
3	19th February	Post-Discuss: Mpemba Effect Pre-Discuss: Thermodynamics: Power Stations	Post-Discuss: Thermodynamics: Power Stations Pre-Discuss: Thermodynamics: Refrigerators
4	26th February	Post-Discuss: Thermodynamics: Refrigerators Pre-Discuss: Projectile Motion	Post-Discuss: Projectile Motion Pre-Discuss: I need a physics police office!
5	5th March	Post-Discuss: I need a physics police office! Pre-Discuss: Today we go to space	Essay Drop-In session
6	12th March	Post-Discuss: Today we go to space Pre-Discuss: Execution of Robbespierre	Post-Discuss: Execution of Robbespierre Pre-Discuss: Hubble, Webb and SKA
7	19th March	Post-Discuss: Hubble, Webb and SKA Pre-Discuss: LIGO	Post-Discuss: LIGO

SCI2038 Task 1

Thought experiments have been used extensively in physics to make significant amounts of progress in this area of science. From demons and cats to buckets and space rockets, physicists have used many examples in the past. They have used this technique to hypothesis how the world works extensively – in particular in areas of modern physics.

As a student of this field, you will often be confronted with situations derived from thought experiments but it is not always clear why we used this technique in sciences or in education (both formal and informal). You should develop a clear definition of thought-experiments and understand how and why these are used.

A successful or useful thought-experiment should be carefully designed – there is a fine balance between radicalism and conformity. In the worst case, a poorly designed thought-experiment can cause stagnation and regression in a field.

Literature

Reiner M. & Burko L.M, 2003 *Science and Education* **12** 365-385

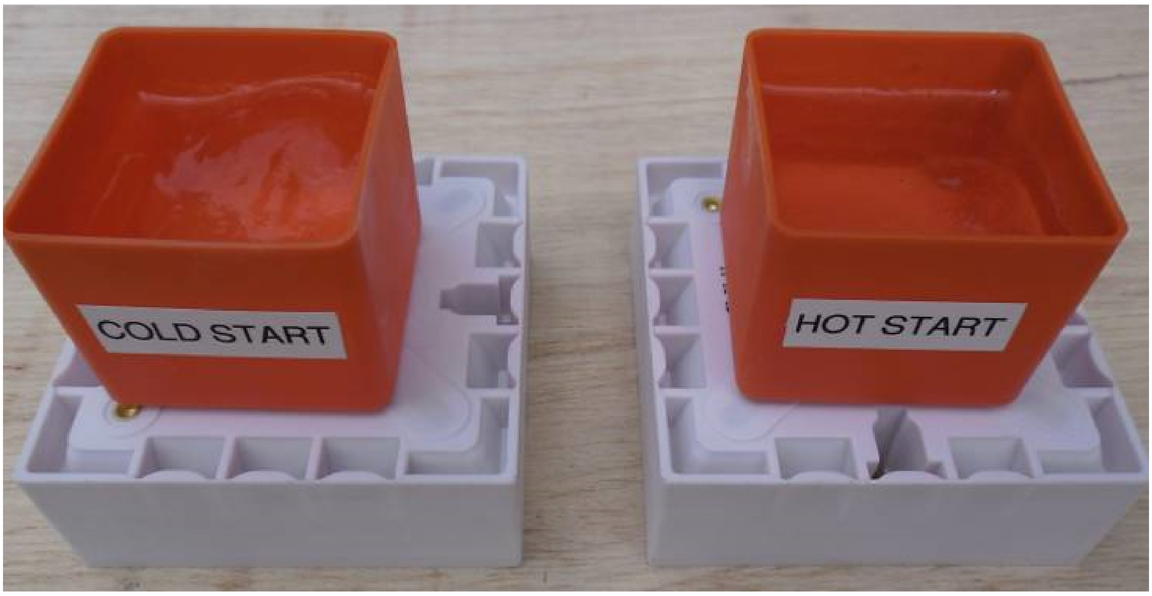
Hammer D, 1995 *Cognition and Instruction* **13** 401-430

Chapter 1 of Young H.D. & Freedman R.A, 2012 *Sears and Zemansky's University Physics with Modern Physics*, Pearson, 13th Edition

There is a physical phenomenon known as the Mpemba effect (named after Erasto Mpemba) which states that a hotter liquid will freeze before a cooler one, when placed in a freezer. This has been summarised by Jeng:

"There exists a set of initial parameters, and a pair of temperatures, such that given two bodies of water identical in these parameters, and differing only in initial uniform temperatures, the hot one will freeze sooner"

Jeng 2006



From a classic thermodynamics perspective, there is no reason why this should be the case, however there are many publications which report finding that this effect does occur.

In 2012, the Royal Society ran a competition about the effect to identify the most viable explanation, despite this, there continue to be much controversy, and the experiment continues to be performed at science fairs and on popular science programmes with regularity.

Literature

Jeng M , 2006 Am. J. Phys. **74** 514 - 522

Mpemba, E and Osbourne, D, 1969 Phys. Educ. **4** 172 - 175

Ball, P 2006 Physics World **9** 19-26

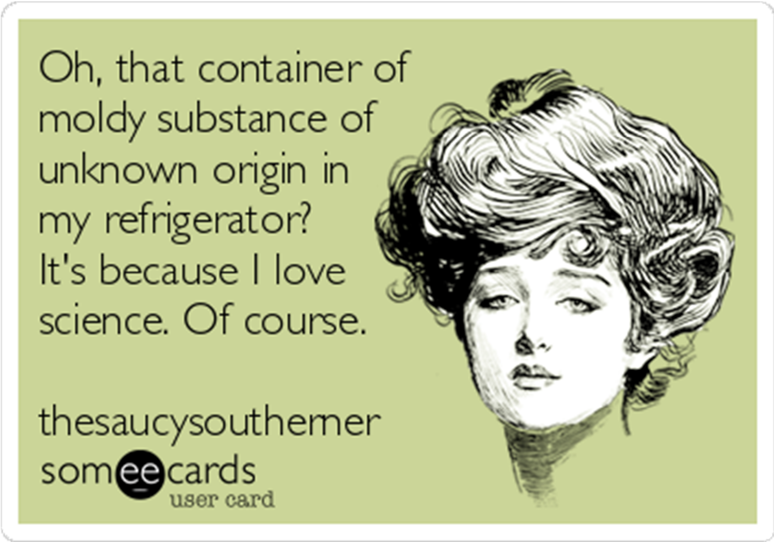
Fossil-fuel based power stations are fundamentally limited in their thermodynamic efficiency by the requirement to release high temperature by-products which wastes heat during the cooling cycle. For a coal or oil fuelled power stations the efficiency is approximately 30%, for gas power stations an efficiency of ≈ 55% is usual. As a result, power plant design is centrally important to ensuring that the remaining thermal energy can be converted to electricity efficiently.

While working on a design for a power station, a company wants to know the best way to design its transportation cycle - moving high temperature steam from the boiler to the turbine room, condenser and back to the boiler in a manner which ensures a high efficiency.

The design is in an early phase and thus the company have set few limitations on what can be achieved, but they need to know how the design of a power station might be adjusted to improve efficiency. If waste (both energy and products) cannot be prevented, it might be harnessed for some useful output.

Literature

Chapters 19 & 20 of Young H.D. & Freedman R.A, 2012 *Sears and Zemansky's University Physics with Modern Physics*, Pearson, 13th Edition



Refrigerators have undoubtedly changed the world in terms of providing longer lasting fresher food to many people in the developed world. They work in a similar way to heat engines – though clearly not in an identical way. A typical electric refrigerator takes in electrical energy and makes things cold.

In a seemingly counter-intuitive experiment, if left alone in a well-insulated (sealed) room, a refrigerator would cause the temperature in this room to increase. In addition, the fridge will obey the third law of thermodynamics.

There was no particular advantage to using the electric refrigerator over other designs – in fact it may have been as a result of a conspiracy that the gas powered refrigerator did not become more popular. The idea of powering a refrigerator with gas seems utterly inconceivable today.

Literature

Chapter 15 of MacKenzie D. & Majcman J (eds.), 1985 *The social shaping of technology (How the refrigerator got its hum),* Open University Press

Chapter 20 of Young H.D. & Freedman R.A, 2012 *Sears and Zemansky's University Physics with Modern Physics*, Pearson, 13th Edition

Muzzle Velocity	$15 \pm 0.5\, m.s^{-1}$	
Angle $(\pm 0.25\,°)$	Time of Flight $(\pm 0.1s)$	Range $(\pm 0.001\, m)$
5.00	0.26	3.846
8.00	0.42	6.115
11.00	0.57	8.311
72.00	2.84	13.040
80.00	2.94	7.568

Projectile motion in general can be used to describe the two dimensional motion of an object launched at some angle with respect to the surface. The force and angle of the launch will determine the distance the object travels. This system can be modelled well mathematically – but considering the motion in each of the directions independently.

From a suitable mathematical model and the data provided, it is possible to determine the maximum range of the projectile in this system and the strength of gravity locally.

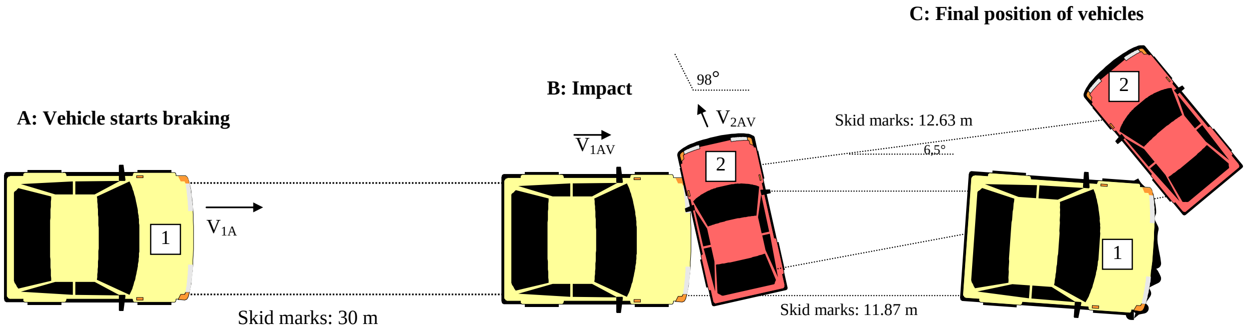
The model most commonly used to describe projectile motion is an idealised experiment – meaning it is incomplete. There is a difference between theoretical value and experimental values for this experiment – there are many physical effects which can account for this difference.

Literature

Chapter 3 of Young H.D. & Freedman R.A, 2012 *Sears and Zemansky's University Physics with Modern Physics*, Pearson, 13th Edition

Adapted from a task by Camil Cyr

Police collision investigators often use classical mechanics and the physics of collisions to establish the cause and blame for accidents. Consider the below picture:



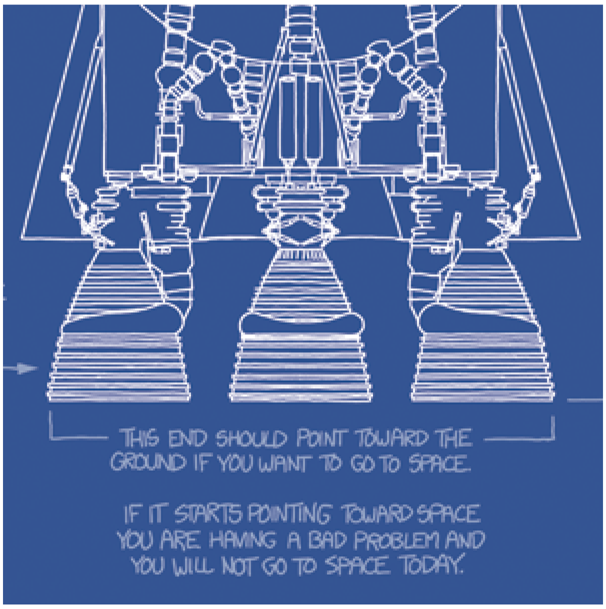
The police have made the following findings at the scene:-

- A significant amount of debris (plastic, metal and glass) has been found at a point 12.63 meters from the red car and 11.87 meters from the yellow car
- The skid lines from the yellow car are in *approximately* a straight line
- The red vehicles skid marks are curved, and it has rotated 6.5° from its original course
- There are skid marks 30 m from the debris
- The mass of the yellow vehicle is 2674 kg and the mass of the red vehicle is 1110 kg.
- A measure of the coefficient of friction using a 9 kg block yields an $F_{tension} = 75.8\,N$.

The collision occurred in a 70 km/h speed limit zone. Which (if either) driver should be blames for this accident, and were they breaking the law prior to it occurring?

Literature

Chapters 5, 6 and 8 of Young H.D. & Freedman R.A, 2012 *Sears and Zemansky's University Physics with Modern Physics*, Pearson, 13th Edition



On December 5th 2014, the first test was conducted on the Orion Multi-Purpose Crew Vehicle – the next-generation hardware which will take astronauts to the moon and beyond. As much as this is a huge step forward for space-exploration, the technology that is being used is broadly speaking identical to that developed at the end of the Second World-War and was used to go to the moon (the first time).

The physics responsible for rocket propulsion is the same as airplanes and hovercrafts – Newton's third law. Essentially this is a result of a "collision"-type interaction between the exhaust and the motor itself.

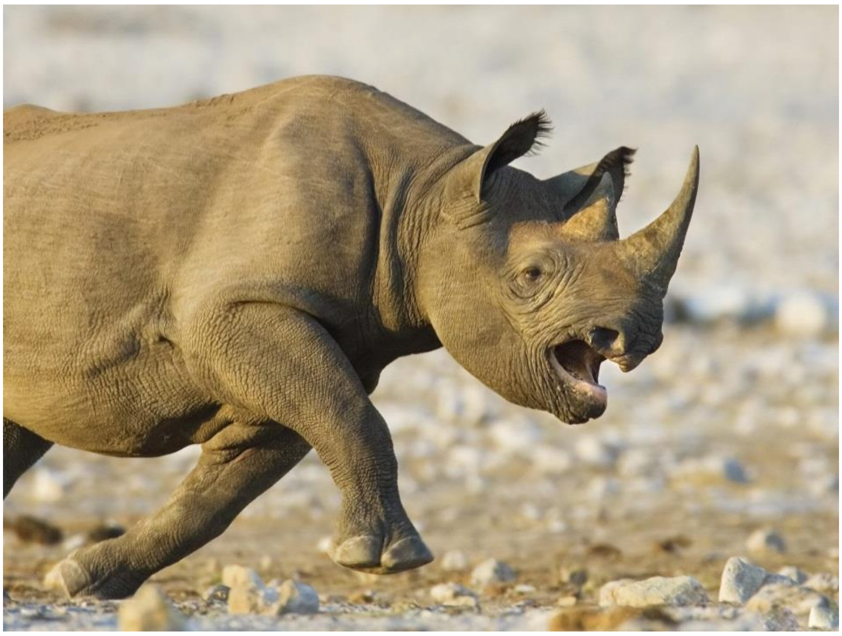
As designs and technologies evolve, we are rapidly approaching the theoretical limits for fuel and the physical requirements for achieving orbit. Mathematically, rocket science is not too complicated (despite what sitcoms might tell us). Find out for yourselves.

Literature

Chapter 8 of Young H.D. & Freedman R.A, 2012 *Sears and Zemansky's University Physics with Modern Physics*, Pearson, 13th Edition

A rhino call Robespierre is sent to the guillotine for his radical behaviour. He is 10 ft long (8 ft body and 2 ft head). The guillotine consists of two blades which descend simultaneously in the frame of reference on the ground and are 8 ft apart.

If the rhino is placed in the guillotine so the first blade missed his tail, he fits exactly and the blade neatly beheads him.



As his last request, the rhino's lawyer asks for him to be wheeled on a cart towards the guillotine – planning to have him pushed at 4/5c – so his length contracts to 6 ft – which means that the blades will miss him.

Robespierre himself is worried, he believes that the distance between the blades will be reduced from 8 ft to 4.6 ft – and he won't escape from being executed.

Who is right, the lawyer or Robespierre? Explain this in terms of **both** the frames of reference of the rhino and the guillotine.

References

Chapter 37 of Young H.D. & Freedman R.A, 2012 *Sears and Zemansky's University Physics with Modern Physics*, Pearson, 13th Edition

26 year ago, the Hubble space telescope was launched in to a low-Earth orbit where it has remained. Despite several space shuttle missions to provide upgrades and repairs, the telescope has not been visited since 2009 and is expected to continue to operate until 2040.

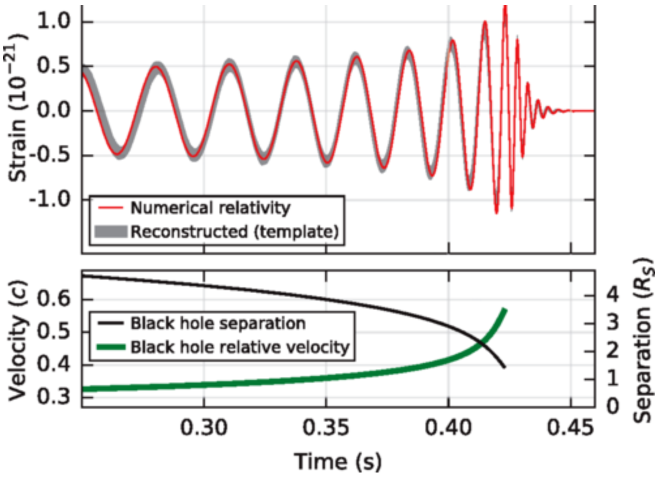
When it was first launched, a fault developed which meant images were of very poor quality, but this was quickly corrected. Hubble has since provided some of the most spectacular images of astronomic bodies in our solar system and beyond. Despite this, there are limitations on the types of objects visible and types of images which can be acquired. On the ground, novel techniques such as ASASSN can provide high resolution and sensitivity rivalling that of Hubble.

In 2018, a replacement telescope is due to be launched, the James Webb Space Telescope, this should provide a new set of tools for astronomers to use. Also in 2018, a telescope with an even higher resolution will start to be constructed call the square kilometre array. Each of these modern techniques compliments the others to provide worldwide capabilities.

Literature

Chapter 44 of Young H.D. & Freedman R.A, 2012 *Sears and Zemansky's University Physics with Modern Physics*, Pearson, 13th Edition

Frundenrich, C & Goddard, S 2000 *How Hubble Space Telescope Works* HowStuffWorks.com URL: http://science.howstuffworks.com/aircraft-hubble.htm Accessed:12 February 2016.



On 11th February 2016, the LIGO collaboration presented unequivocal evidence of the existence of gravitational waves for the first time at a press conference in Washington, USA. This work, completed by a large multi-national collaboration is further evidence of the genius of Albert Einstein, who predicted their existence over 100 years prior to their discovery.

The fact that Gravitational waves exist tell us something extremely fundamental about the Universe and they indirectly explain why we won't float off into space but also how distant massive objects interact with the rest of the Universe.

Gravitational waves are extremely difficult to detect and therefore make measurements of, but they contain a significant amount of information about distant objects and their properties. Their discovery provides an incredibly exciting step forward in the state of physics in the wider world.

Literature

Abbott, B, 2016 Phys. Rev. Lett. **116** 060112

Chapter 37 of Young H.D. & Freedman R.A, 2012 *Sears and Zemansky's University Physics with Modern Physics*, Pearson, 13th Edition

Problem Statement

How do we detect and measure gravitational waves?

(Possible) Learning Goals

- What are gravitational waves and what do they tell us about the Universe?
- How does LIGO work?
- What happened to create the gravitational waves measured in the paper?
- How does the signal measured tell us about the behaviour of the distant objects?

Literature

Participants are directed to a chapter from Young and Freeman as guidance for reading as well as the paper from the LIGO collaboration.