Physics for future Presidents

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Topics for student presentations

Towards the end of this semester you will give a presentation on a physics related subject in recitation. I ask you to pair up with someone else in your recitation and pick a topic about which you will report. This may involve research on a specific subject or even conducting a simple study or experiment. You and your project partner will contribute to the preparation of the material and the final presentation, which is expected to take about 15 minutes. Per recitation, any given topic can be picked only once. You will be graded on this presentation, and this will contribute 5% to your final grade for this course.

The research topics on the subsequent pages are examples of what you can do. Every one of them should make for an interesting subject which provides ample material and can largely be understood based on the physics you have learned in class (if there are some remaining small gaps, you would be responsible to fill them in). Should you feel, however, that there's a topic not on this list that you would rather like to talk about, you are highly encouraged to come forward with a suggestion. In this case I would ask you and your project partner to prepare a one-page outline of the topic you have in mind (similar maybe to a typical page in the subsequent notes) and show me this outline. Based on it I will decide whether or not you can go ahead with your choice. I simply want to make sure that whatever you have picked is both appropriate and that you will likely be able to find enough interesting and relevant material.

Don't procrastinate! Topics will be handed out on a first-come-first-serve basis. You should as soon as possible find a partner with whom you want to do a project, look with them through the subsequent notes, and decide whether any one of them (or a self-proposed one) is what you'd like to go for. Remember that it takes time to do the research (or the experiments) and that you need to distribute presentation responsibilities evenly.

Finally: be mindful that you will not just be graded on *content* but also on *presentation*. This involves: having well-designed slides, making sure the audiovisual equipment works, staying within the allotted time, making an effort to be pedagogical, speaking clearly and being understandable all the way to the back row, while avoiding any number of speaking affectations that are widely regarded as bad form and will almost surely hurt you professionally if you indulge in them—think of valley up-talk, vocal fry, mumbling, excessive use of fillers ("uhm", "like", "you know", "okay"), and informal language ("stuff", "whatnot", "dude").

1 The physics and technology of 3D movies

A fair number of movies that have recently been released are "in 3D". You get a pair of special glasses and experience the movie three-dimensionally. Objects appear to protrude out of the flat movie screen, the impression of true depth arises. In this presentation you are asked to explain, how this works and how it is done.

Examples of questions to address

- Why does one need two eyes to perceive objects three-dimensionally? Can't I look at a cube with just one eye and still tell it's three-dimensional?
- What is the purpose of the glasses you get?
- How are 3D-movies filmed? How are they projected in the movie theater?
- What is the basic principle behind essentially all current 3D technologies?
- A variety of different technologies exist that all have been used to make 3D movies: RealD, IMAX 3D, Dolby 3D, LCD shutters, etc. Review some of these technologies. What are the similarities and differences?
- What is linearly or circularly polarized light, and which technologies make use of them?
- What are advantages and disadvantages of certain technologies?
- What are the technological challenges to make 3D television?

Notes

- Make sure you address the physical questions of this topic.

2 Measuring the acceleration of everyday motions

Many modern laptops and cell phones are equipped with *accelerometers*—sensors which register the way in which the device is accelerated. Together with additional software we are then capable to plot the acceleration which the device experiences. It is instructive to see how everyday motions are registered on such devices.

This project has a strong experimental component.

Basic idea

While we have a very intuitive feeling of *velocity*, our understanding of *acceleration* seems to be somewhat less firm. In fact, confusing these two concepts is a major source of trouble even for beginning physics students. For example, the direction in which we move and the direction in which we accelerate do not necessarily have to coincide. If we're jumping up, we move up, but Earth's acceleration is directed downwards nevertheless. In this project you should investigate the acceleration associated with some "typical" motions we undergo in everyday life.

Examples of questions to address

- In which direction do we accelerate in an accelerating car, or a breaking car? What about a car going through a curve at constant speed?
- What is the acceleration in an elevator? Going up? Going down? While starting? While stopping?
- What is the acceleration on an escalator?
- Try dangling your device on a spring or bungee cord (at your own risk...). Can you graph acceleration, speed, and position as a function of time?
- Can you relate these experiments to the notion of "weightlessness" and "apparent weight"?
- What is the acceleration if you drop the laptop (for a short while, and catching it carefully afterwards!)
- Before "gaming" became a common application of the accelerometers in Laptops (and later phones), they were used for something more profane. What was this, and how did it work? The official name of the accelerometer – "sudden motion sensor" – is a give-away.

Notes

- This project requires you to be somewhat familiar with computers. You will also need to analyze the "acceleration files" using some suitable software (e.g. Excel). You might want to show the output of these files graphically in your presentation and point to interesting things, such as: "And here the elevator starts slowing down" or the like.
- To make your presentation more lively, you might want to document your experiment by taking some pictures!

3 Measuring the height of buildings with a smartphone

Many modern laptops and cell phones are equipped with *accelerometers*—sensors which register the way in which the device is accelerated. Using the output of this sensor, and a little bit of data processing, we can determine the height of a building by measuring the accelerations we experience while going up or down the elevator. In this project you should do such an experiment an measure the height of a building, for instance Wean Hall.

This project has a strong experimental component and requires a bit of nontrivial math (calculus!).

Basic idea

The change of position with time is called velocity. The change of velocity with time is called acceleration. If we know the change in position we can determine the velocity, and from there we can also determine the change in position. It is conceivable that if we know the acceleration an object is subject to, we can work out the velocity, and from there the position. This is not hard in principle, and we can have a computer do the calculation. If we now take a smartphone with a built-in accelerometer, the data of which we can store and further process, we can measure the change in position of that phone from the knowledge of the acceleration it was subject to. So, if we ride with that phone from floor 1 to floor 8 of Wean Hall, we should be able to tell what the height difference between these floors is!

Examples of questions to address

- What is the basic idea of the experiment?
- How did you execute the experiment in practice?
- How do you subtract the constant acceleration of the Earth?
- What is the speed of the elevator?
- What is the result you got? How accurate do you think it is?
- What are the major sources of error?
- What other applications of this "experimental technique" can you imagine?
- Can you relate these experiments to the notion of "weightlessness" and "apparent weight"? At what points during the elevator ride is your apparent weight more than your actual weight?

Notes

- This project requires you to be somewhat familiar with computers. You will also need to analyze the "scceleration files" using some suitable software (e.g. Excel).
- Groups who choose to execute this project should first meet with me to discuss a possible way for how to implement the experiment and its analysis.
- To make your presentation more lively, you might want to document your experiment by taking some pictures!

4 The physics of musical instruments

Musical instruments create sounds when we treat them properly, which might involve plucking strings, hitting keys, moving a bow over a string, blowing air into them, etc. The ways in which the sound is ultimately created and amplified, and how the pitch is changed, involve all kinds of beautiful physics concepts. In this presentation you're asked to illustrate this with a few examples.

Examples of questions to address

- What are the major principles by which musical instruments create sound?
- How are a piano and a violin similar? How are they different?
- How are a trumpet and a trombone similar/different?
- What is the "harmonic series", and how is it exploited in some instruments?
- How does an ocarina work (this is a hard one)?
- How does "chiming" a guitar string double the sound frequency? Describe the motion of the string.
- Why do different musical instruments sound differently, even if they play the "same" note?
- You can get free software that permits you to visualize sound on a computer. Explore, how waveform and spectrum differ between different instruments or the human voice. What changes if you go one octave up?
- What digitizing rates are required to reproduce a sound that seems accurate to the human ear? Would this be different for a dog's hearing?

Notes

- If you play a musical instrument yourself with which you could help illustrating some of the points you want to discuss in your presentation, it might be a great idea to bring it to class on that day, and give a live demonstration. (Unless, of course, you play double bass, piano, or any other difficult-to-transport instrument.)
- Don't forget that you should focus on physical concepts.

5 Cochlear implants

At times it seems amazing how far medical technology has advanced. For instance, if your hearing degrades, then depending on the specific condition responsible for this loss of hearing you might be eligible to try to get a "bionic ear", properly termed a "cochlear implant". In this project you're expected to inform us, what this is and how it works.

Basic idea

Everyone of our standard human senses (such as vision, sound, taste, smell, touch) works by some specific set of receptor cells being stimulated, possibly after the incoming signal got processed in some clever way. For instance, they eye processes the incoming light and creates an image on our retina, where light sensitive cells finally get stimulated and send electrical signals to the brain. Likewise, the outer and middle portion of our ear processes sound waves in some clever way, and guides them into our inner ear, where vibrations in an organ called the "cochlea" stimulate nerve cells which then send signals to the brain which we perceive as sound. If these nerve cells fail to function, they can be crudely replaced by an artificial system called a cochlear implant. You're supposed to discuss the ins and outs of this.

Examples of questions to address

- How does the ear function – from the sound coming in to the electrical signals finally being sent to the brain?
- What is the cochlea and what happens in there?
- Explain the (approximate) relation between stimulating a specific region in the cochlea and hearing a specific sound.
- What type of hearing loss can be partly fixed by a cochlear implant?
- What is the main functional principle of the implant?
- What is the history of cochlear implants? How many people wear them today?
- What is the difference between a cochlear implant and a "standard" hearing aid?

Notes

- Some aspects of this problem have a strong medical or physiological component. Don't get carried away by all the names and the bio jargon. Try to extract the essential physics and focus on that.
- Some of the relevant physical processes are more complicated than what you will be able to describe. Don't despair. There's always a simple approximate version of the "scientific truth" which should be enough for now, as long as we don't forget that, deep down, things are more complicated (well, as they always are).

6 The physics in sports and games

Physical exercise is also an exercise in physics. Very often fundamental physical concepts play an important role if you want to be good at a particular sports activity. In this presentation you're expected to discuss some examples for this.

Examples of questions to address

- Why is it hard to cycle uphill? Can we quantify this?
- What's the physics behind the famous "Fosbury Flop" in high jump?
- What's the physics of an ice-skater's pirouette? (Or of ice skating to begin with.)
- How do springboard divers control the number of rotations they perform before hitting the water?
- How do you "bend it like Beckham"? (Also called a "curl", i.e., how do you kick a soccer ball so that it flies a curvy path?)
- How does "spin" work in tennis or table tennis or baseball (where it's called a "curveball")?
- How do you throw a discus really far?
- What determines the flight of a javelin?
- How does the mass of a football player affect the speed he can run, or how quickly he can achieve that speed?
- A good NHL player can shoot the puck at speeds exceeding 100 miles per hour. Certainly, he can't move the hockey stick this fast, so how does this work?

Notes

- If you practice a particular sport yourself, feel free to concentrate on this one. But you still must focus on the physics, not simply "sports lore".
- There is a lot of *good technical information* about this topic available in books and on the Internet. Don't delude yourself into winging it just because you're good at sports; this is a science project!

7 Measuring the speed of sound in air

Sound in air travels at a fast speed, something like a mile in five seconds, but it's not so fast that we couldn't measure it with comparatively simple experiments. In this project you're asked to determine the speed of sound in air by very simple means.

This project has a strong experimental component.

Basic idea

Since the speed of sound is finite, any noise made at some point A (say, by Alice) takes some time to travel to a distant point B (where it's heard by Bob). Since the speed of sound is not *that* fast, Bob doesn't have to be too far away from Alice in order to notice the delay. For instance, if Alice and Bob stay 100 meters apart and Alice claps her hands, Bob sees the hands touching but hears the clap about 0.3 seconds later. If Bob claps in his hands exactly at the same time at which he hears the clap, his clapping sound will reach Alice again 0.3 seconds later, which is 0.6 seconds after she clapped for the first time. Hence, by establishing some kind of synchronized clapping between Alice and Bob (which then would be something like one clap every 0.6 seconds), we can determine the speed of sound by measuring the exact time between claps (which can be done quite accurately by stopping the time it takes for, say, 10 claps).

Examples of questions to address

- What is the basic idea of the experiment?
- What is the "synchronization problem" and how did you take care of it?
- How did you execute the experiment in practice?
- What considerations go into the chosen distance?
- What is the result you got? How accurate do you think is it?
- What are the major sources of error?
- Some measurement techniques involve the time delay between seeing an event and hearing the sound of the event (think of the *crack!* you hear when a batter hits a baseball, which appears to happen shortly after you saw him hitting the ball). How does the speed of light come into this?
- Laptops and smartphones have apps that allow you to visualize a waveform. Can you observe the sound of a clap and the echo of the clap if you stand in front of a brick wall?

Notes

- Groups who choose to execute this project should first meet with me to discuss a possible way for how to implement the experiment.
- To make your presentation more lively, you might want to document your experiment by taking some pictures!

8 The Marcellus Shale Gas Reserves

The Marcellus Shale is a sedimentary rock formation in the northeastern part of the United States. It contains considerable amounts of natural gas that could be recovered. In this project you are asked to present this topic from various perspectives.

Examples of questions to address

- What exactly is the Marcellus Shale? How old is it, and how do we know that?
- Why does it contain natural gas?
- What are the estimates for the content of natural gas, and why do they differ so much?
- What are the economic considerations that must go into plans for recovering this gas?
- What is "fracking"?
- What are the environmental considerations?

Notes

- You might find it hard to put much physics into this presentation. But still try to be at least scientific, meaning that you substantiate your claims with good data and make some quantitative estimates.
- You might hold (possibly strong) political views on this topic. But beware: This is *not* supposed to be turned into a propaganda show for or against fracking. We want to learn the scientific basis of the debate, not the political ramifications.

9 Solar and wind power

Renewable energy sources are a hot topic in the modern debate about a sustainable energy economy. In this project you are asked to provide some details about solar and wind power.

Basic idea

If we talk about "alternative energies", two questions always come up: First, what type of alternative energy generation model do we look at? Second, how can we try to make it economically viable? Both questions, even the economical one, touch on physical and technological issues. Some of these you're expected to discuss here.

Examples of questions to address

- What are the ways in which solar and wind energy are used?
- What is the kinetic energy of the air that flows through a 100m diameter disk if it is moving at 10 mph during 1 second? What is the power? Can a 100m diameter wind turbine extract all that energy? What are the limitations?
- Think about the issue of "big plants" that serve many houses versus small units that go with an individual house.
- What are the economic considerations that should go into such technologies and their use?
- What is the current use? Are there differences across the world?
- What might the future be for these energy sources?
- What are the challenges? What are the limitations?

10 The Global Positioning System (GPS)

For a small sum of money you can buy a little piece of equipment that tells you with an accuracy of maybe 10 meters where on Earth you are. This is a true modern miracle that we nowadays tend to take for granted. (But think what Christopher Columbus or Ferdinand Magellan might have thought!) In this project you're asked to explain to us in some more detail how GPS works.

Examples of questions to address

- What is the general principle?
- Where are the satellites, and how many are there?
- Why does the system require accurate clocks? And how accurate do they have to be?
- How is GPS used nowadays?

11 False white and spectral lines

White light really consists of a mixture of many other colors. White light from the sun or an incandescent light bulb indeed contains all the colors of the rainbow. But this need not be true for every light that appears white to our eyes. In this project you are asked to investigate light sources and report on your finding.

This project has an experimental component.

Basic idea

If white light is a mixture of different colors, how do we “unmix” it and get these colors back? This can be done by using prisms or diffraction gratings. An example of a prism is almost any oddly shaped piece of glass which, when sunlight falls on it, emits rainbow-colored light. An example of a diffraction grating is the surface of a CD or DVD, which under light also shows the characteristic rainbow reflections. Hence, using a CD or DVD we can “unmix” the light not just of the sun, but of many other light sources.

Examples of questions to address

- How do prisms and diffraction gratings work? You do not need to give a very detailed explanation, but try to get the main principles right!
- What is the difference between the spectrum of the sun and that of a neon light?
- Look at different light bulbs. Can you tell whether they are incandescent or compact fluorescent bulbs by looking at their spectrum of light?
- Why is it smart to look at very “localized” lights (“point sources”) rather than a possibly very bright source which however has a large extension?
- Groups who chose to execute this project should first meet with me to discuss a possible way for how to implement the experiment.
- To make your presentation more lively, you might want to document your experiment by taking some pictures!

12 Optics

Vision is one of the most basic senses of humans. We're largely "visual animals". Correspondingly, the manipulation of light to enhance our vision – e.g. the building of telescopes and microscopes – has been around since the beginning of science. Galilei famously built a telescope and discovered the moons of Jupiter (and then got into trouble for claiming heretic things about them). Much optics relies on a remarkably simple device: a lens. You're supposed to discuss what one can do with these beautiful little things.

This project can be amended by an experimental component.

Basic idea

Light is a wave, and its direction of propagation can be changed by interactions with materials. If these pieces of matter are suitably shaped, the change of direction of light can be finely controlled and cleverly exploited. The results are telescopes, microscopes, cameras, glasses, etc. You're supposed to discuss how a single lens works, and how simple devices can be built out of it. You're also encouraged to redo some of the simple experiments and illustrate the effects.

Examples of questions to address

- What is refraction?
- How does a lens work?
- What type of lenses exist? How are they characterized?
- What is the basic principle behind a microscope and a telescope?
- What is the Hubble space telescope? What was the COSTAR system with which Hubble got retrofitted in 1993, and what was the result of that?
- How does "diffraction" limit our ability to see small things?
- How does the wavelength determine the size of things we can see?
- What is an electron microscope, and why can it see things much smaller than an optical microscope? Can you imagine other devices that can see things much smaller than what is visible with, well, visible light?
- Can you build a microscope and a telescope out of two lenses? Can you show in class?

13 The cold fusion story

On March 23rd 1989 Stanley Pons from the University of Utah and Martin Fleischmann from the University of Southampton held a press conference in which they announced the results of some electrolysis experiments they had done with heavy water and a palladium cathode. Based on calorimetric data (essentially, measurements of the heat emitted by their device) they suggested that the deuterium produced at the cathode, after being absorbed by the metal, in which it would be at an appreciable density, might have undergone nuclear fusion which would be the source of the excess heat. This sounded like the beginning of a fantastic scientific saga, but it turned out to be a start of one of the biggest science fiascos in recent history. You're expected to retell this story.

Basic idea

Fusion is the process by which the nuclei of lighter elements combine into heavier elements. This releases an enormous amount of energy. It is the process which fuels the sun and is the source of energy of a hydrogen bomb. Since the nuclei contain positively charged protons but no electrons (they "orbit" the nuclei at a *much* bigger distance), all nuclei repel, and it takes a considerable energy to get them close enough together so that they can fuse. This energy is usually thermal energy, and this means you already need a very hot material in order to induce fusion. (In other words, not only is the sun hot because fusion happens inside it; without the high temperatures inside its core it couldn't support fusion in the first place.) It is this high temperature which makes it so hard to replicate fusion in a controlled (read: non-bomb-like) way in the laboratory. All the more exciting were the findings of Pons and Fleischmann, who alleged that with almost laughably simple devices they could trigger sustained deuterium fusion under room temperature. Could this really be? As usual, if big claims of this kind are made, hundreds of scientists drop whatever they had been working on right now and try to see for themselves whether this could be true. This was the begin of the controversy.

Examples of questions to address

- Explain the basic physics of fusion.
- Why would "cold" fusion be something special? In other words, how does cold fusion contrast to the more familiar hot fusion?
- What is the experiment that Pons and Fleischmann did? What did they suggest happened?
- What was the criticism brought forward by other scientists?
- What are "rules of good scientific practice", and how did Pons and Fleischmann violate them?
- What are the roles played by fame and money?
- What is the current status?

14 Running out of Helium?

Helium is an inert noble gas that is used in a surprisingly large number of important technical applications. There are fears that we might run out of it on Earth in the not-so-distant future. In this presentation you're expected to investigate this story.

Basic idea

Helium is very light, that's why we can also use it in balloons to make them float (through buoyancy). Just like hydrogen it will escape our atmosphere when released, but *unlike* hydrogen there is no substantial source of helium on Earth from where we could simply take more. It is a noble gas, so it does not form molecules with other atoms and is therefore not available in chemical compounds (unlike hydrogen, which is available for instance in water). So in a very real sense helium is much less replaceable than hydrogen once it has escaped. Since it is important for technical applications, this is a serious source of worry.

Examples of questions to address

- Where does most of our helium come from?
- How long do people think our supplies might last?
- You can check out that Helium is the second most common element in the universe, making up something like 25% of all the (baryonic, *i. e.*, "ordinary") mass. Why then is there so little on Earth?
- What are some of the applications for which helium is vital?
- Are there ways to make helium? How much could we make? What would it cost?
- What is the difference between Helium-3 and Helium-4? Does it matter for the present discussion?