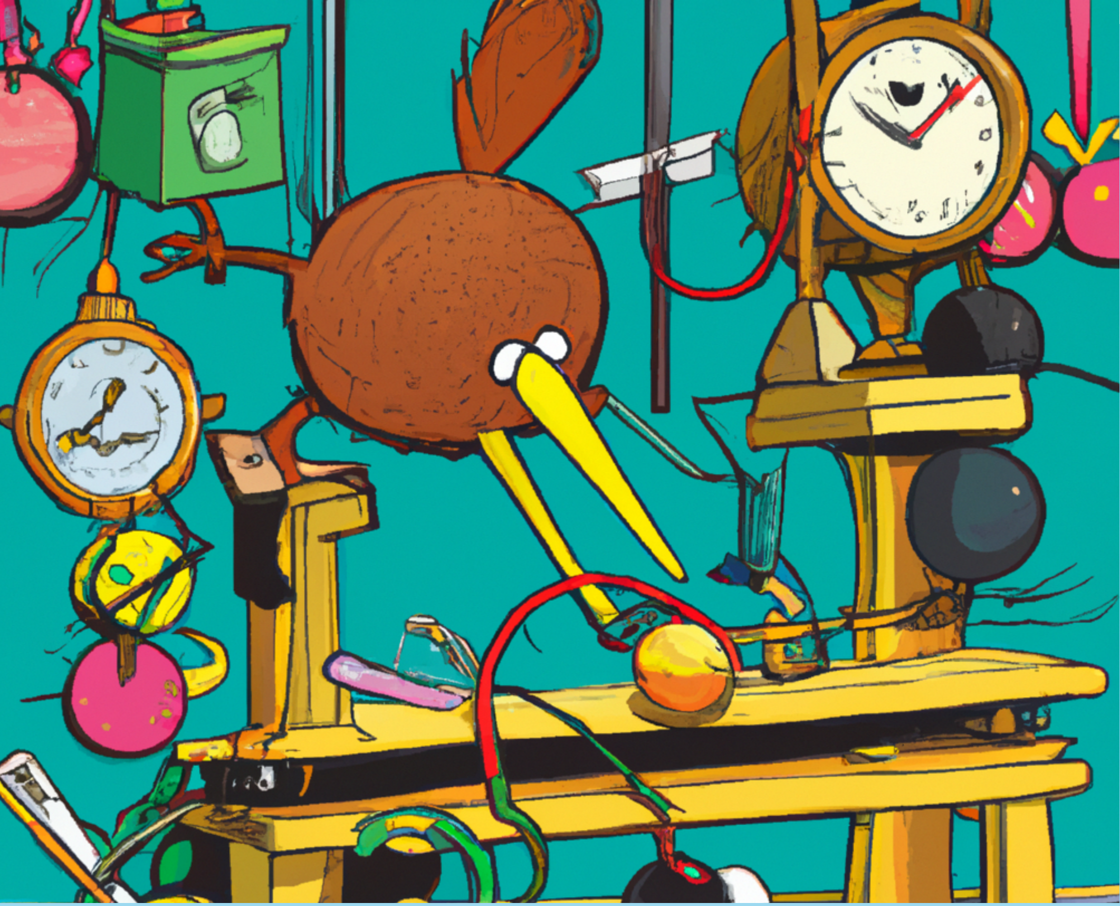

Otago Scholarship Physics

2024 edition

A booklet of physics questions

University of Otago
ŌTĀKOU WHAKAIHU WAKA

Otago Scholarship Physics

Question booklet – 2024 edition

Questions written and compiled by
your friendly lecturers from the Physics Department
at the University of Otago

Please get in touch with us at physics.office@otago.ac.nz to hear more about a physics degree, request additional copies of this booklet, or provide feedback, suggestions, or corrections. We'd love to hear from you!

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Dear Physics Student

Physics is not a spectator sport! Solving lots of different problems helps us to understand new concepts and develop really valuable skills.

Students planning on sitting the NZQA Scholarship Physics Exam[1] will be expected to solve many challenging problems. This is where we can help. This booklet collects problems and answers from several years worth of the Otago Scholarship Physics Facebook page.

Who are we? Some physicists from the University of Otago who love solving problems.

What do I do? Each page has different questions with a level and subject similar to the NZQA scholarship physics exam. They are ordered roughly by subject and difficulty, but there's lots of cross-over, which is part of the fun of scholarship compared to normal NCEA.

How do I know I'm right? Every question comes with fully worked solutions that you can use to check your approach and results. These are supplied in a separate answer book. If you have a better solution, let us know!

Curious about a physics degree and the amazing career opportunities it unlocks? We have included some useful information at the back of the booklet.

Regards from the OSP team at Otago,

Jonathan, Daniel, Nick, & Blair

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[1]Even if you don't plan on taking the Scholarship exam, these problems will be useful for developing your physics skills.

Problem solving strategies

Many of the questions in this booklet are *tough*! Don't get discouraged if you can't immediately see how to get started.

Most people, when presented with a tricky problem, jump too quickly into trying to solve equations – don't fall into this trap! We suggest (based on lots of previous research[2]) **starting with a sketch or picture**, which will help you come up with **a plan of attack**. As you do this, you might want to consider:

- Restating the problem in your own words.
- Writing down a list of physical principles that might be relevant or useful (e.g., energy conservation).
- What type of result are you after – numerical or algebraic? And what be would a "reasonable" answer?
  (You shouldn't be finding that a ball rolls down a hill at 10kms^{-1}…)

Only once you've thought through these should you start "calculating," following your plan of attack.

Finally, don't forget that you haven't finished until you've thought about your answer – ask yourself:

1. Are the numbers reasonable?
2. Does your solution have a limit (e.g., some parameter = 0) for which you know the answer and can cross check?
3. Are units consistent through all stages of your calculation?
   (e.g., if you sum two quantities with different dimensions, it's wrong)

You'll notice we cover most of these steps in most of the worked solutions. But (as always) the best advice is – practice!

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[2] See e.g., Physics for Scientists and Engineers, Debora Katz (2015), which is the textbook we use for our main first-year physics courses at Otago.

Using this booklet

This booklet is not necessarily designed to be followed from start to finish (though you can certainly do this if you'd like). The questions are ordered into their primary subject areas (*Mechanics, Waves & SHM, Modern Physics,* and *Electricity & Magnetism*), but by design, there is **a lot** more overlap between subjects than you would find in the usual NCEA curriculum. To help you pick out questions, each one comes with various "concept symbols" that indicate the concepts and/or techniques that might be needed. The hardest problems are also marked with the challenge symbol ( ) although your opinion might vary, so don't be put off!

Detailed solutions for all problems are provided in the separate answer booklet.

Concept symbols:

- Energy conservation
- Forces/torques
- Momentum
- Kinematics
- Rotating systems
- Oscillating systems
- Waves: Interference
- Waves: Doppler
- Circuits
- Nuclear & particles
- Magnetism

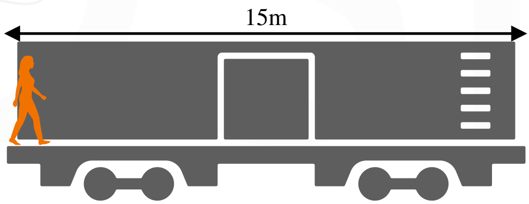
Mechanics

M1 - Why Did the Sheep Cross the Road?

A sheep suddenly crosses the road 90m ahead of a car travelling at a speed of $30ms^{-1}$. It takes the car 60m to stop, including the 0.5s it takes for the driver to react and apply the brakes (the sheep is clearly relieved). How far would it have taken the car to stop if instead it had been travelling at $40ms^{-1}$? Does the car hit the sheep? If it does, what speed is the car traveling at the point of impact?

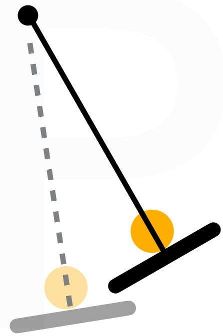
M2 – Train Trotting

Li, who is 50kg, is standing on the left-hand side of a 2000kg, 15m long train cart, which sits on frictionless rails.



Suddenly, she starts jogging to the right with a speed of $3ms^{-1}$ (compared to the cart), continuing until she drops off the end of the cart. You're watching from the ground on a nearby track and record the position of Li and the cart as a function of time. **Draw a graph of what you see** (the position of Li and the cart versus time). Label important features such as Li's and the cart's speeds (the lines' slopes) and Li's position when she drops off the end.

M3 – Swing Drop



You rest a ball on a swing, pull it back to 45 degrees, and let it go. Does the ball fall off, and if so, to which side?

NB: (i) You may ignore the effects of air resistance
(ii) The swing platform stays perpendicular to the rope.

M4 – Fiery Flying

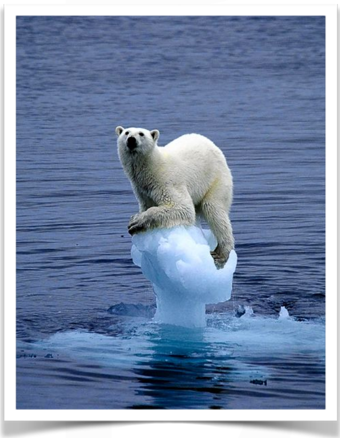
You're team physicist for daredevil motocross rider Courtney Duncan, who wants to jump over a flaming bus. Her plan is to launch off a 10m high, 40m long flat platform, over the bus, then onto the ramp on the other side.

However, in order to properly land the jump at such high speeds, she must hit the ramp exactly on its left edge, with a velocity vector that lines up exactly with the angle of the ramp (20°). Given that her bike can accelerate at $5ms^{-2}$, how tall should you build the ramp, and where should it be positioned?

M5 – A Nasty Bungee Jump

Your friend Arihia is about to bungee jump off an 80m high bridge. She has worked out that for her head to just touch the water, she will need a bungee cord that is 25m long (when unstretched). However, you're feeling mischievous and decide to replace her cord with a slightly longer one made of the same material, so that her head gets dunked 30cm under the water. How much longer should you make the bungee cord?

M6 – Buoyant Bears



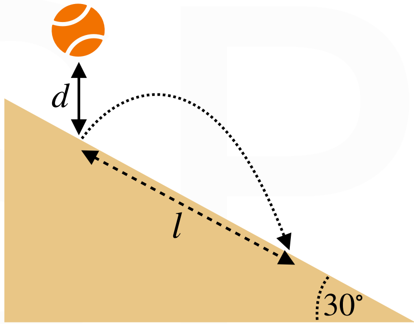
A 1000kg polar bear stands on an iceberg, which is slowly melting and sinking. What is the minimum volume of iceberg needed to keep the poor polar bear above the water (assuming she doesn't like wet feet)?

Hint: the buoyant force upwards on an object is equal to the weight of the fluid that it displaces.

NB: Cold sea water has a density of 1030kgm^{-3}.
Sea ice has a density of 920kgm^{-3}.

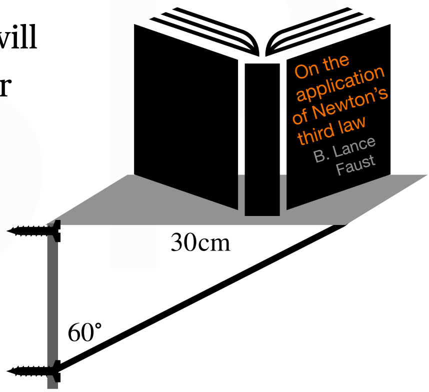
M7 – Bouncy Balls

You drop a perfectly elastic ball from a distance *d* above a 30° ramp. How far down the ramp (*l* on the diagram) does it land?



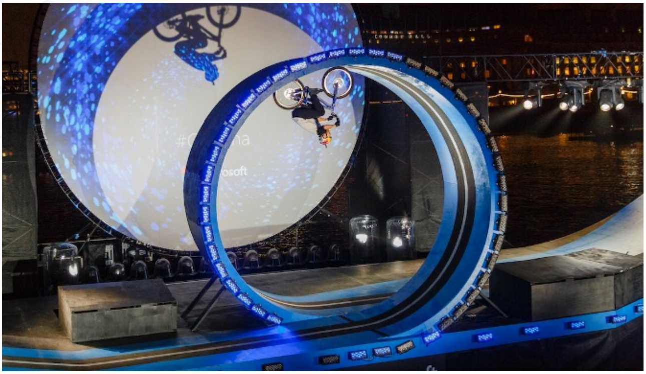
M8 – Balancing Bookcases

Remy is building a bookcase, which will protrude 30cm out from the wall. Her design uses a strut attached between the wall below and the outer side of the shelf. It makes an angle of 60° to the wall. The shelf and the strut are attached to the wall by screws.



In order to design the setup, she needs to know how much force the screws will need to support, in both the up/down and in/out directions. Help her work this out, given that she has 10kg of books that will be positioned with their centre of mass in the middle of the shelf. You can ignore the weight of the shelf and the strut.

M9 – Loops (and why you should listen to the physicist)



You're the resident physicist on the team of cycling legend Danny MacAskill, who wants to do a loop the loop on his bike. The builders have built a tall, 10m high ramp, that he will roll down to gain speed without pedalling, and want to know the height of the biggest possible loop that Danny can do without falling off. What diameter can they make the loop? (assume he is a frictionless point mass, and neglect the spinning of the bike wheels).

Part (b) – After you tell them, the team ignore you and decide to build a loop with the same diameter as the height of the ramp (10m) because they think it will look cooler. Realising Danny is going to fly off the loop somewhere in the middle, you decide to take matters into your own hands and find a crash pad to rush into the place where he'll land. Where will Danny hit the ground? (ignoring the fact that the loop might be in the way of his trajectory).

M10 – A Hanging Spring

In this problem, we will answer the (seemingly) simple question **"How much does a massive spring stretch when we hang it from the ceiling"**? It has mass M and spring constant k.

If you think you know how to do this - skip to part (d)! If not, follow along:

A. Pretend all of the spring's mass is concentrated in the middle and at the end (two masses $M/2$ with two sections of massless spring). How much does this system stretch?

B. Repeat a) but now with N springs and N masses of M/N. Show that the stretch of the bottom spring is $gM/(kN^2)$. Add the N springs together to find the total stretch.

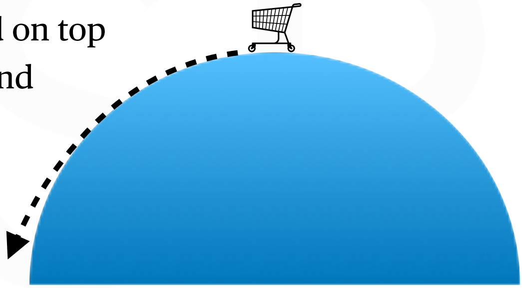
C. Take the limit as N approaches infinity to find the stretch of a massive spring.

D. Sketch the tension force in the spring along its length, assuming the stretch is small compared to the spring's length.

E. (*Challenge*) Steel has a density $\rho = 8000\text{kgm}^{-3}$ and an "elasticity" (Young's modulus) of $200\text{kgm}^{-1}\text{s}^{-2}$. How much does a 1m long circular steel bar with diameter 1cm stretch when you hang it from the ceiling?
(Hint: if you're unfamiliar with elasticity think about its units.)

M11 – Hemispherical Hill

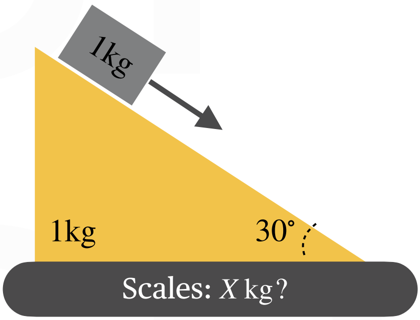
A frictionless cart is placed on top of a 10m tall hemisphere and starts sliding downwards from rest. How far above the ground is it when it leaves the hemisphere's surface?



M12 – Sliding Scales

a) A 1kg block slides down a 1kg 30° frictionless ramp. The whole system rests on a set of bathroom scales. What do the scales read?

b) Replace the block with a 1kg solid ball that rolls without slipping – what do the scales read?



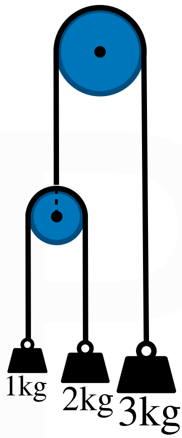
NB: A solid ball of radius r and mass M has moment of inertia $I = \frac{2}{5}Mr^2$.

M13 – Asteroid Crash

A SpaceX Starship rocket, which is shaped like a long thin tube, is parked at rest in interplanetary space, awaiting its approach to Mars. Suddenly, an asteroid, with a velocity that is perpendicular to the Starship, hits the Starship on one end, losing so much kinetic energy in the collision that it comes to rest in the pre-collision frame of the Starship. As the Starship starts spinning in circles, the crew must figure out how to stop it and get back into position. Help them out by calculating the ratio of the Starship's translational to rotational kinetic energy after the collision.

NB: a massive rod of length L and mass M has moment of inertia $I = \frac{1}{12}ML^2$ *about its centre.*

M14 – Double Pulley



Does the 3kg mass move up or down? What is its acceleration?

NB: the lower pulley can spin freely while attached to the rope. Pulleys and ropes are frictionless, massless, and inextensible.

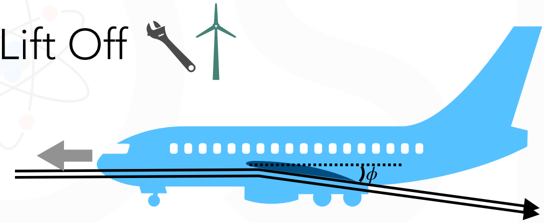
PS. The answer is not that it stays still!

M15 – Mine Timing

While walking around central Otago, you come across an impressively deep mine shaft – a hole so deep you can't see the bottom. After making sure there's no-one down there, you decide to figure out its depth by dropping rocks down the hole. You time multiple measurements, finding it takes an average of 3.34s until you hear the crash of the rock hitting the bottom. **How deep is the mine?**

NB: You may not neglect the speed of sound, $c_s = 343\text{ms}^{-1}$, in making your estimate. But, you can safely neglect the air resistance on the rock.

M16 – Lift Off



A simple model for an airplane wing stipulates that it generates lift by deflecting air downwards as it moves forward. For this problem, we will apply this model to a Boeing 737. The wing has width 3m and a length of 20m on each side. You can assume that it is thin, making an angle to the horizontal, which determines the volume of air pushed downwards. The 737 weighs 45000kg, and the density of air is $\rho \approx 1\text{kgm}^{-3}$.

How fast must the 737 fly in order to stay at constant altitude? How much power must the engines supply in order to fly at this speed without accelerating?

M17 – The Space Elevator

You've been assigned by NASA to assess the viability of a design for a "space elevator." This is a cable of constant thickness that will stretch up to space from the equator, which is so long that it simply hangs there, touching (but not attached) to the ground. Once built, getting to space would be as simple as taking a (rather long) ride up the elevator, without the enormous cost of a rocket.

A. Consider a small section of cable somewhere in the middle of the elevator. Draw and label the forces on the section from the cable itself (above and below the section) and gravity. How must these forces add together for the cable to stay up and orbit with the same frequency as the Earth's rotation?

B. Thinking carefully about what must happen at its ends, sketch the tension in the cable as a function of length along the full length of the cable. Using reasoning about forces, at what length (above the centre of the Earth) is the tension maximum?

C. You figure out that the tension force satisfies,

$$T = -\frac{GM_e}{r}\mu - \frac{1}{2}r^2\omega_e^2\mu + T_0$$

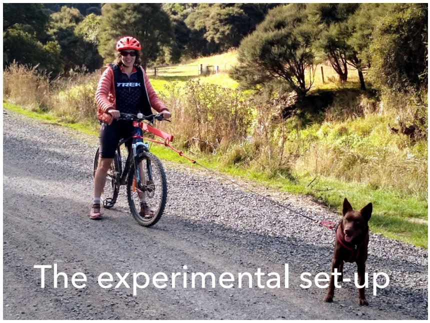
where M_e is the mass of the earth, ω_e is its rotation rate (in radians s^{-1}), r is the distance from the centre of the Earth, μ is the mass per unit length of cable, and T_0 is an undetermined number. How long does the space elevator need to be?

(If you're stuck, try using an online cubic solver, but know that it's possible to get a simple answer without this.)

Earth mass = 5.98×10^{24}kg   Earth radius = 6370km $G = 6.67\times10^{-11}$Nm^{2}kg^{-2}

Waves & Simple Harmonic Motion

W18 – Canine Cycling



Upon joining my friend for a bike ride, I found that she had brought an assistant with her. When I pointed out that this was a little unfair, she argued that in fact the amount of help provided was tiny, and I should find a better excuse for being unable to keep up!

Can you help us work out how much easier the dog made the ride?

A. At one point in the ride we measured that the dog's lead, which ran from the bike to the dog's harness, was vibrating in its fundamental mode with a frequency of 5Hz. Given that the lead is 5m long and weighs 200g, what was the tension in the lead?

B. At the time we made this observation, we were riding at a steady speed of 7kmh^{-1}. How much additional power is being provided for the cyclist by the dog?

C. How does this compare to the power of an e-bike? A keen amateur cyclist? A professional road cyclist during a sprint finish?

NB: The velocity of a wave on a string is $c_w = \sqrt{T/\mu}$ *where* T *is the tension in the string and* μ *is its mass per unit length.*

W19 – Driving into Doppler

While driving at 50kmh^{-1}, you approach a stationary ambulance with its siren blaring:

- At what frequency will you hear their 440Hz siren?
- The ambulance pulls out and drives towards you at 50kmh^{-1}. What is the siren's frequency now?

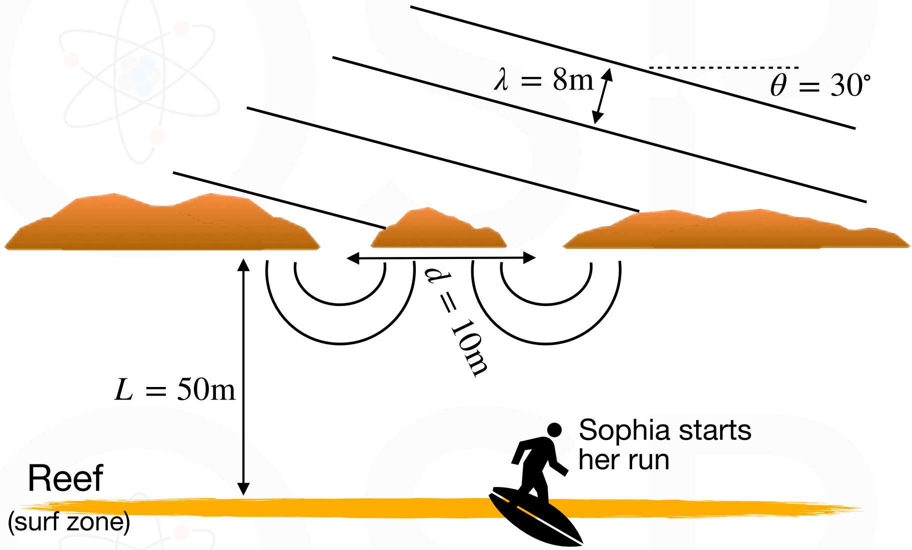
NB: the standard Doppler-shift formula, $f' = f\, v_w/(v_w \pm v_s)$, applies when the source of the wave (with frequency f) moves with velocity v_s, in a medium where the wave propagates with velocity v_w. Use diagrams and physical reasoning to derive the more general cases needed above.

W20 – Bouncing Around

A 100g mass hangs off the ceiling from a massless spring, which has spring constant k = 4Nm^{-1} and length L = 75cm (when unstretched). You give it a tug, pulling it 1cm down and 1cm to the right. Sketch the path that the mass traces out as it oscillates around. What are the potential and kinetic energies as a function of time? On your sketch of the mass's path, label the points at which it is going fastest and slowest.

NB: For simplicity, use g = 10ms^{-2} in any calculations.

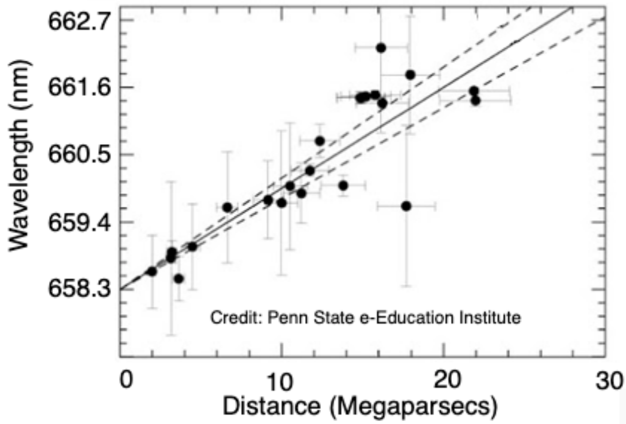
W21 – Interference Inlet



The famous surf break, interference inlet, has waves break on the reef 50m behind two narrow gaps formed by some rocks that are 10m apart. Sophia is keen to surf the biggest waves. The forecast tells her the direction of the swell will be at angle 30° to the rocks, while its wavelength is 8m. Find the position(s) along the reef where Sophia should start from for the most exciting ride. How many choices does she have?

Challenge: can you work this out without using the small-angle approximation?

W22 – The Age of the Universe

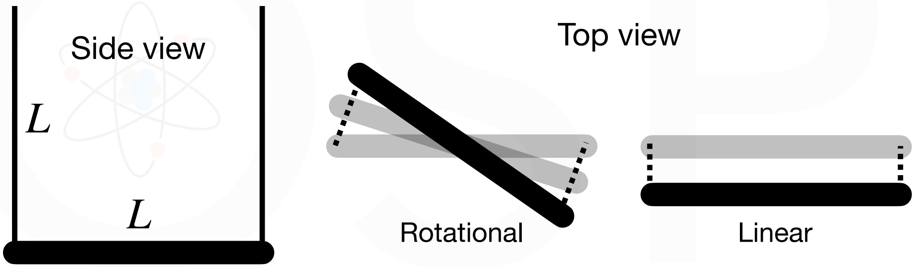


Each point on the plot above shows the measured wavelength of the hydrogen-alpha absorption line for light from a different galaxy. The galaxies are located at random locations in the sky around the Earth. The error bars indicate the range of measurements within a given galaxy, and the solid line shows a linear fit to the data. The measured rest-frame wavelength of the hydrogen-alpha line from the lab is 658.28nm. **Estimate the age of the universe.**

NB: the standard Doppler-shift formula is not in general correct for light waves, because of relativistic effects. But, for these relatively small Doppler shifts, it works just fine.

The "parsec" = 3.26 *light years, is the astronomer's distance unit*
1 *Megaparsec* = 3.26 *million light years* = 3.1×10^{19} km

W23 – Rod Rotations

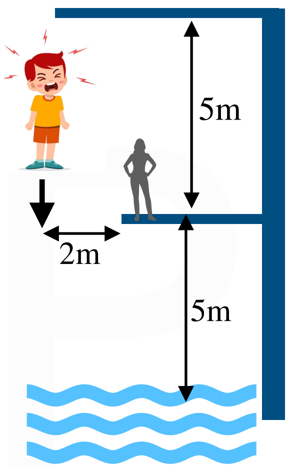


A solid rod of length L is strung up at its ends by two strings of length L. The setup allows two types of oscillatory motion – linear, like a normal pendulum, or rotational, with the rod twisting back and forth. What is the ratio of their periods?

NB: The moment of inertia of a rod of mass M about its centre is $I = \frac{1}{12}ML^2$

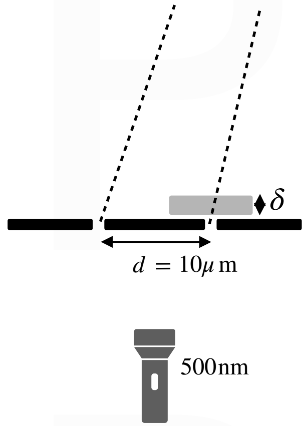
W24 – Doppler Diving

Mark jumps off the 10m diving board and screams his head off – it's a perfect A (880Hz)! You stand on the 5m board, which 2m back from the 10m board, so that Mark is 2m away from you when he passes by falling vertically. What frequency do you measure as a function of time, starting at $t = 0$ when Mark leaves the 10m diving board? Sketch your answer as a graph, labelling important features.



W25 – Interference Interfering

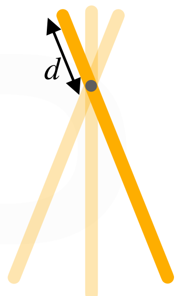
You set up a double-slit experiment with a 10μm wide slit and 500nm light, which creates a characteristic interference pattern on a far-away screen. Then, in front of one of the slits you place a very thin glass plate. The glass has refractive index $n = 1.5$, which means that the light's wavelength decreases by a factor n within the glass. After inserting the plate, you notice that the peaks of the interference pattern lie in the same positions as they were before the plate was inserted. **How thick is the glass plate?**



Hint: You can think of the effect of the glass as increasing the distance the light travels within the plate by a factor n. All angles can be assumed small.

W26 – Swaying Sticks

A solid rod of length L is secured a distance d from its end by a bearing that allows it to rotate back and forth. What is the period of its pendulum motion for small displacements from the vertical?

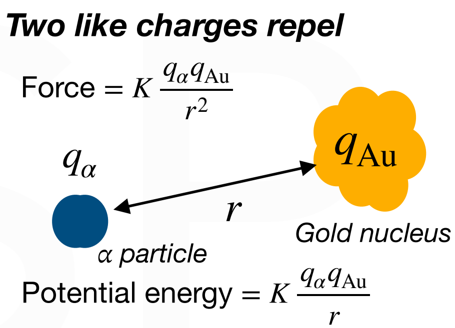


NB: the moment of inertia of a rod of mass M about a point a distance ℓ from its centre of mass is $I = \frac{1}{12}ML^2 + M\ell^2$.

Modern Physics

Q27 – How Big is the Nucleus?

Ernest Rutherford's famous experiment showed that when alpha particles scatter off gold atoms, the pattern they make is exactly what one would expect from the interaction of two, very small radius, point-like charges. Rutherford realised that this also means that the alpha particles never "hit" the nucleus, because otherwise it would change the pattern. Given that the alpha particles in the experiment (which came from radioactive Radium) have a speed of $2.0 \times 10^{7}\,\mathrm{ms}^{-1}$, and that the potential energy of two charges interacting is $K\dfrac{q_\alpha q_{\mathrm{Au}}}{r}$ (see diagram), what did Rutherford figure out was the **maximum possible diameter of a gold nucleus implied by the experimental results?**



Useful constants: Atomic mass unit = $1.66 \times 10^{-27}\,\mathrm{kg}$

$q_{\mathrm{Au}} = 79e$, $q_\alpha = 2e$, with $e = 1.6 \times 10^{-19}\,\mathrm{C}$

Coulomb's constant $K = 9.0 \times 10^{9}\,\mathrm{Nm^2C^{-2}}$

Q28 – Solar Sailing

The quantum-mechanical nature of light implies that, as well as carrying energy $E = hf$, a photon carries momentum $p = h/\lambda$. Here f is the frequency of the light and λ is its wavelength. Use this principle to design a “Solar Sail” that uses the Sun’s light to accelerate a 1-ton spacecraft from the Earth to Mars (180 million km) in one year. How big a sail is needed? Should it be dark or reflective?

NB: The intensity of the Sun’s light at the radius of Earth is 1370Wm^{-2}. You may ignore the variation in this intensity with distance from the Sun.

Q29 – Supersymmetric Snooker

You are a particle physicist studying the decay of a new particle called the *sneutron* (symbol sn) into *sprotons* (sp^+) and *selectrons* (se^-). Selectrons are easy to measure – they are long lived and easily seen in the cloud chamber – so you have measured their mass as 5.5u (where u = 1.7×10^{-27}kg is the atomic mass unit). But sprotons, which are heavier than selectrons, are notoriously difficult to measure because they rapidly decay into other particles. You measure that in all reactions, the initially stationary sneutrons, which have a mass of 511u, decay into selectrons with a kinetic energy of 231MeV.

What is the mass of the sproton?

NB: You may ignore relativistic effects in computing particle velocities.

Q30 – Kilogram Conundrums

In 2019 the International Bureau for Weights and Measures (BIPM) redefined the kilogram by setting the Planck constant h to be exactly *6.62607015×10^{-34} kg m^{2}s^{-1}. Before this, the kilo was defined by a lump of platinum-iridium alloy in Paris known as the urkilogram, which was used to calibrate other masses. At the same time, the BIPM redefined Avogadro's number to be* exactly *6.02214076×10^{23} particles per mole (rather than the number of atoms in 12 grams of ^{12}C). The second is defined to be* exactly *9192631770 oscillations of the microwave radiation emitted by the hyperfine ^{133}Cs transition, and the metre is defined by setting the (vacuum) speed of light to be* exactly *299792458 ms^{-1}.*

This question concerns whether various quantities or objects have associated error, or whether they are exact. As an example to get started, the speed of light is exact (it is used as the definition), and so is the wavelength of hyperfine ^{133}Cs radiation ($\lambda = c/f = \frac{299792458}{9192631770}$ m, since f and c are exact). But, the speed of a car is not (it must be measured) and nor is the wavelength of Balmer-series radiation emitted by Hydrogen atoms. For each case below, work out the value (e.g., 1kg for A) and discuss whether they are exact or not in the pre- and post-2019 unit systems.

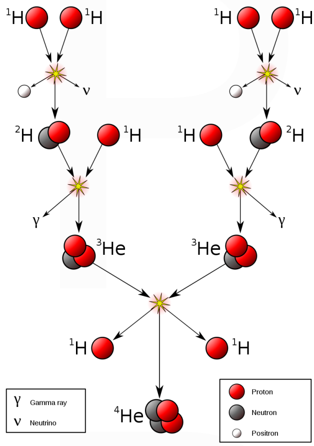
A. The mass of the urkilogram in Paris?

B. The number of atoms in 1 kilogram of ^{12}C?

C. The difference in mass between 10^{40} ^{133}Cs atoms in their excited (hyperfine) state, and 10^{40} ^{133}Cs atoms in the ground state?

D. The difference in mass between 1kg of ^{133}Cs atoms in the ground state and the same number in their excited (hyperfine) state?

Q31 – How Long Until the Apocalypse?



Credit: wikipedia.org: Sarang

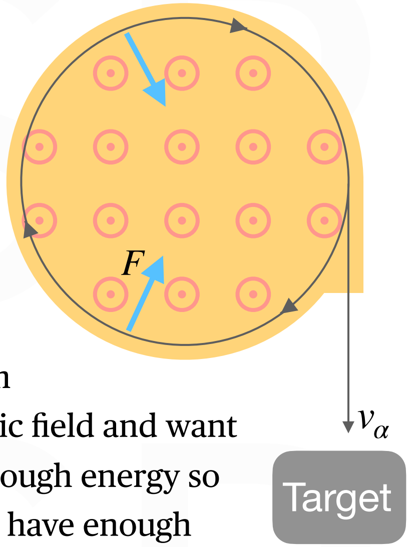
The main process by which the Sun converts Hydrogen to Helium (^{4}He) in its core to power all life on Earth involves 3 sets of reactions. First, two ^{1}H combine to form a Deuterium ^{2}H nucleus (plus a positron and neutrino) releasing 1.44MeV. Then, the ^{2}H combines with ^{1}H to make ^{3}He (plus a gamma ray) releasing 5.49MeV. Then finally, two ^{3}He combine to create two ^{1}H nuclei and a ^{4}He nucleus, releasing 12.86MeV. Use this information, along with the fact that the flux of energy reaching the Earth from the sun is approximately 1373Wm^{-2}, to estimate how long the sun can survive before it runs out of fuel and explodes.

Useful constants: Mass of ^{1}H $= 1.67 \times 10^{-27}$kg

Earth-Sun separation $= 1.496 \times 10^{8}$km

Mass of the Sun's core $\approx 6.7 \times 10^{29}$kg

Q32 – Cyclotron



In a magnetic field of strength B, a particle of charge q feels a force $F = qvB$, acting in the direction perpendicular to its velocity v and the magnetic field. You use this concept to design a "cyclotron," which confines fast-moving α particles and shoots them into a target. You have a 2T magnetic field and want to shoot the α particles out with enough energy so that, when they hit the target, they have enough energy to overcome their binding energy and split into two neutrons and two protons.

What is the minimum radius of the cyclotron?

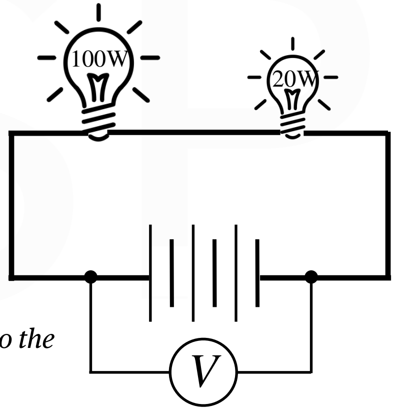
Useful constants: α particle mass $= 6.6447 \times 10^{-27}$kg
proton mass $= 1.6726 \times 10^{-27}$kg
neutron mass $= 1.6749 \times 10^{-27}$kg
proton charge $= 1.67 \times 10^{-19}$C
speed of light $= 3 \times 10^{8}$ms^{-1}

Electricity & Magnetism

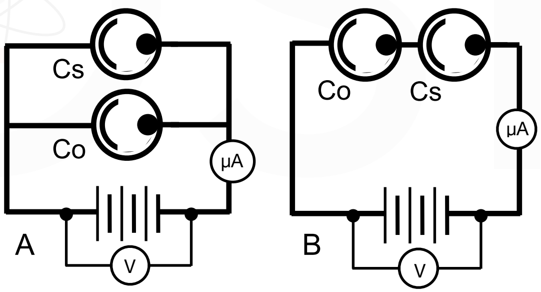
E33 – Lightbulbs

You connect a 100W and a 20W incandescent lightbulb as shown. How bright is each bulb? In other words, how much power is dissipated in each?

NB: If a lightbulb is rated to 100W, it dissipates 100W of power when hooked up to the voltage source on its own.



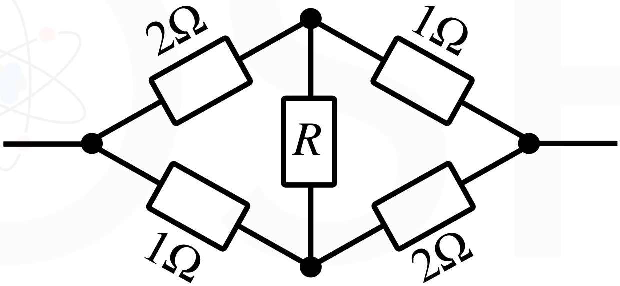
E34 –Photo-eclectic



You are given two photoelectric cells; the first is made of Caesium, with a work function $\Phi = 2.1\text{V}$, the second is made of Cobalt with a work function of $\Phi = 5.0\text{V}$. Being the curious type, after wiring them up separately you decide to measure the stopping potential V as a function of frequency when they are put together in one circuit.

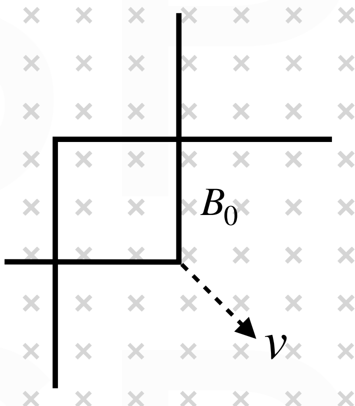
What do you find for cells in: (A) parallel (B) series?

E35 – What's the Resistance?



Hint: start by imagining an applied voltage between the two ends then apply $V = IR$ and/or Kirchhoff's laws across each section.

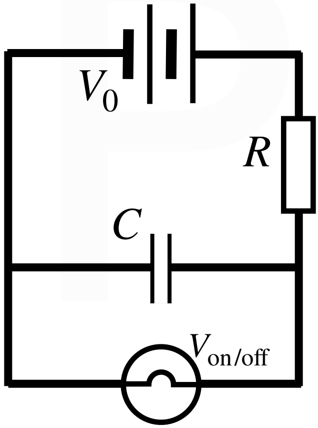
E36 – In Flux



Two L-shaped wires are crossed to form a square and in a constant magnetic field $B_0 = 1\text{T}$. Grabbing a corner of one of the L's, you give it a pull, causing its point to move down and to the right as shown, with constant velocity $v = 1\text{ms}^{-1}$ at a 45° angle. Given that the wire has a resistance of $1\Omega\text{m}^{-1}$, how much force must you apply to keep it moving at 1ms^{-1}? You start, at time $t = 0$, with the corners of the two L's just touching each other (i.e., no loop at all).

NB: You can neglect the self-inductance of the wire loop in your calculation.

E37 – Neon Lights

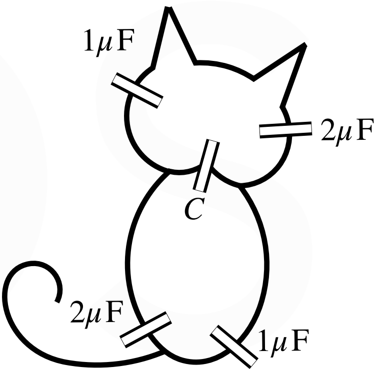


Your friend Maia has just opened a cafe, and wants a flashing neon sign to attract attention. She's come up with the design on the right, where the circle at the bottom indicates the neon tube. This has the property that it turns on when the voltage across it reaches $V_{\text{on}} = 90\text{V}$, but doesn't turn off until the voltage drops below $V_{\text{off}} = 30\text{V}$. When it is on (emitting light), it has nearly zero resistance.

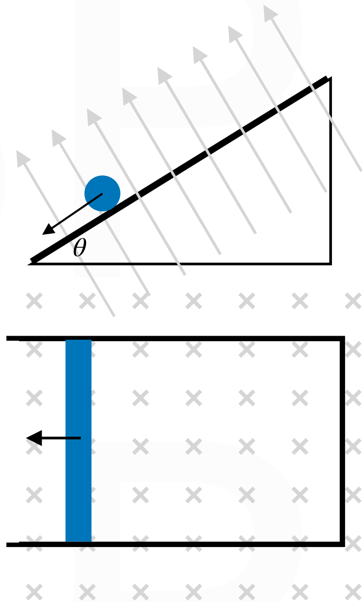
Describe how Maia's circuit works. Given that the power supply has voltage $V_0 = 120\text{V}$, and the capacitor is $C = 300\mu\text{F}$, what sized resistor should Maia choose if she wants the light to flash at 1Hz? Averaged over one period, what is the power output of the neon tube?

E38 – What's the Cat-acipance?

(As measured between her ear and her tail)



E39 – Magnetic Mountain

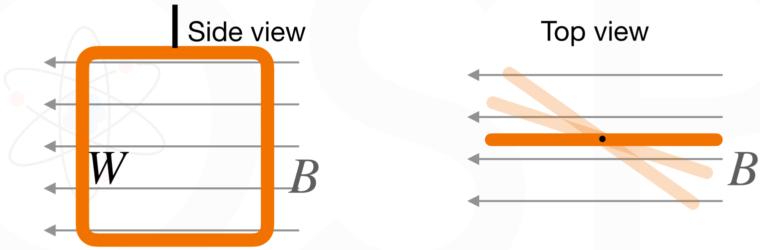


A rod, which has resistance $R = R_0\Omega$ and length ℓ, slides down a frictionless track, which is at an angle $\theta = 30^\circ$ to the horizontal. The track is made of a perfectly conducting wire and makes a perfect electrical connection to the rod. The whole system is threaded by a uniform magnetic field, which is perpendicular to the ramp. Some time after you release the rod, it stops accelerating and reaches a constant velocity v.

A. What is v?

B. Describe the motion of the rod if – instead of being perfectly conducting – the rod and the track are made of the same wire, so that the track has finite electrical resistance.

E40 – Inductor Oscillations



A square loop of wire of very low resistance with side length W hangs in the Earth's magnetic field, which has strength $B = 50\,\mu\text{T}$. Such a loop has an inductance of $L = (2\mu_0/\pi)W$, where $\mu_0 = 4\pi \times 10^{-7}\text{Hm}^{-1}$. The loop can rotate freely, and initially hangs with its long axis parallel to the magnetic field, as pictured.

A) Using basic reasoning about the current induced in the wire as it rotates, explain why the loop will oscillate back if rotated away from the parallel direction.

Hint: remember that the force on a wire of length B, carrying current i, in magnetic field B, is $F = BiW$.

B) For a loop with mass $M = 1\text{g}$ and size $W = 1\text{cm}$, what is the period of its simple harmonic motion for small oscillations?

NB: the moment of inertia of a rod of length W and mass m secured about its centre is $I = \frac{1}{12}mW^2$.

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Te Tari Hū-o-te-Kōhao, the Department of Physics at the University of Otago, was the first Physics Department established in New Zealand, and physics was a foundation discipline when the University opened in July 1871. Today, the Department embraces innovative teaching methods, promotes a vigorous research ethos, and is committed both to Physics as a discipline and to its applications. Our key objectives are to provide students with the highest quality education, and to produce research of international excellence.

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