The Purcell Club

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Contents

1 What Is The Purcell Club/Order Of Magnitude Estimates Club?

This document contains a series of Fermi problems published in different editions of the American Journal of Physics by Edward Purcell (yes, the author of the renowned E&M textbook) from January 1983 up until May 1988. The problems were published under the column name "The Back of the Envelope" and they were usually published in sets of three, with solutions for the previous month's problems appearing in the next set. These problems continued to be featured monthly for about a year and a half before Edward Purcell stopped publishing them regularly - but they did not stop completely until May 1988.

This document serves two purposes: (1) it is a collection of all of Purcell's problems which I've numbered in the order they were published. I did this to allow for convenient counting of the total number of problems and because LaTeX's referencing feature which will make it easier for me to index them during our Order Of Magnitude Estimation Club (OOMEC) meetings on Tuesday afternoons and (2) this document will allow me to type up our own solutions to these problems which we can then cross-check with Purcell's own solutions.

For the purpose of doing the problems, the PDF file included in this project, titled "1983-01.pdf" includes Purcell's reference sheet for different physical constants, material properties, and whatnot.

2 January 1983 [1]

2.1 Problem 1: Escape From An Asteroid

How big of an asteroid could you escape from by jumping?

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2.2 Problem 2: How many nucleons can fit in a tea cup

If a tea cup could be made impervious to nucleons, how many neutrons could it hold, at absolute zero, without running over? How many protons? (Note: typo in the solution - should have $frachm\sqrt{2gy}$)

2.3 Problem 3: Energy Radiated By Bouncing A Basketball

Rubber gloved, you are dribbling on an infinite court a basketball that is charged to 10 kV. How much energy is emitted as electromagnetic radiation per bounce?

3 February 1983 [2]

3.1 Problem 4: Can A Helium Balloon Lift A Helium Tank

Can a helium balloon lift the tank the helium came in?

3.2 Problem 5: Balancing A Pencil On Its Point

At room temperature in still air, how long can a pencil remain balanced on its point? How long at absolute zero?

3.3 Problem 6: Longest Free Path Of A Nitrogen Molecule

Estimate the length of the longest free path experienced by any nitrogen molecule in the lowest kilometer of the Earth's atmosphere within the last billion years

4 March 1983 [3]

4.1 Problem 7: Expelling An Electron From The Solar System

Would an electron exposed only to solar radiation pressure and gravity be expelled from the solar system? (note: see correction in December 1983 letter)

4.2 Problem 8: A Straight Line Hitting The Earth

What is the probability that a straight line drawn from the Earth in an arbitrary direction (but not toward the sun) will hit a star in this galaxy? Assume 10^{11} solar type stars and 10 kpc to the galactic center.

4.3 Problem 9: Filling In The Blank Dimensional Analysis

A ____ of water contains about as many molecules as there are ____s of water in all of the oceans. What goes in the blank: drop, teaspoon, tablespoon, cup, quart, gallon, barrel, or ton?

5 April 1983 [4]

5.1 Problem 10: Airplanes In Random Flight Without Crashing

What is the largest number of airplanes that could be in blindly random flight, over the continental United States, and between $15,000$ and $30,000$ ft altitude, without risking more than one fatality per billion passenger miles as a result of midair collisions?

5.2 Problem 11: Earth's Core Polymorphed Into A Wire

If the iron in the Earth's core were made into a wire as long as the radius of the visible universe, what would be the diameter of the wire?

5.3 Problem 12: The Planck Mass Expressed As Energy

The "Planck Mass" is defined as $\sqrt{\frac{hc}{G}}$. As energy, what is this worth in gallons of gasoline?

6 May 1983 [5]

6.1 Problem 13: Smallest Diameter Of An Earth Satellite

A star like the sun is just about visible to the naked eye if it is 50 light years away. If you want to put up an Earth satellite in the form of a reflecting sphere that can be seen as it passes over at night, what is the smallest diameter it may have?

6.2 Problem 14: Diffusion Recycling The Air In A Cup

A paper cup on the table is empty, except for the air it contains. The surrounding air is perfectly still. What is the best guess for the time it will take diffusion to replace half the air molecules in the cup with new molecules: a second, a minute, an hour, or a day?

6.3 Problem 15: A Sunny Day's Worth Of Energy Expressed In Cubic Miles Of Coal

Define a "sun day" as the amount of energy received by the whole Earth in one day from the sun. The entire U.S. coal reserves have been estimated at 10 sun days. How many

cubic miles of coal does that amount to? How does it compare with the amount of carbon in the Earth's atmosphere, of which about 1 molecule in 3000 is CO_2?

7 June 1983 [6]

7.1 Problem 16: Completely Converting Earth's Magnetic Field Into Usable Energy

If the energy stored in the Earth's magnetic field could be drained with no losses and used to supply the world demand for electrical power, how long would it last?

7.2 Problem 17: Guitar String Sagging

A guitar string tuned to G ($392\,\text{Hz}$) sags in the middle, owing to its own weight, by what distance?

7.3 Problem 18: Removing Electrons From Earth's Electric Potential

If the electrons in one raindrop could be removed from the Earth without removing the protons, by how much would the potential of the Earth be increased?

8 July 1983 [7]

8.1 Problem 19: Conduction Electron In A Kilometer Long Circuit

A copper wire $1\,\text{km}$ long is connected across a $6\,\text{V}$ battery. How long does it take a conduction electron to drift around the circuit at room temperature?

8.2 Problem 20: Transmitting The Humane Genome Over A Video Channel

How long would it take to transmit over a video channel the information contained in the human genome, approximately $1\,\text{m}$ of DNA?

8.3 Problem 21: Heat Engine Water Jet

A perfect heat engine, or combination of heat engines, has as its only input equal amounts of hot water at $90\,\text{degC}$ and cold water at $10\,\text{degC}$. As its only output it squirts all this water out in one high-speed jet. What can you say about the temperature and speed of the water in the jet? (note: see correction in December 1983 letter)

9 August 1983 [8]

9.1 Problem 22: Radio RMS Field Strength CMB Comparison

How far from a $1\,\mathrm{kW}$ radio transmitter is the RMS electric field strength equal to that in the cosmic microwave background? (Note: see corrections in December 1983 letter)

9.2 Problem 23: Amount Of Water Needed To Reduce The Range Of Visibility In Fog

If water is dispersed as a fog of droplets all of the same diameter, and if that diameter can be chosen to achieve the greatest opacity for a given amount of water, estimate the amount of water, in grams per cubic meter, required to reduce the range of visibility through the fog to about 10 meters.

9.3 Problem 24: Longest Batting Slump Of Famous MLB Legend Monty Carlo

The ball player Monty Carlo is a genuine .250 hitter. In every official time at bat (walks, etc. not counted) the probability that he gets a hit is .250. In Carlo's record for the season, which included 300 official times at bat, what is likely to be the length of his longest slump, that is, run of consecutive hitless official times at bat? What is the probability that his actual batting average for the season exceeded .300?

10 September 1983 [9]

10.1 Problem 25: Amplitude Of Vibration Of Air At A Speaker Aperture

A loudspeaker aperture 12 inches in diameter is putting out 5 W of acoustic power at a frequency around 500 cps. Estimate the amplitude of vibration of the air at the aperture.

10.2 Problem 26: Readability Of The Entire Library Of Congress Printed On A Postcard

Hyper-reductions, Inc. announces a fantastic process capable of putting the contents of the Library of Congress, in facsimile, printed with tungsten, on a very smooth postcard. Will it be readable with an off-the-shelf electron microscope?

10.3 Problem 27: Exposure Time Needed To Capture A Well-Exposed Picture

On the beach at noon, with a clear sky, you made a good snapshot at $\frac{f}{8}$ and $\frac{1}{500}$ s. At midnight the same scene is lit by the full moon. You want to make an equally well-exposed picture. You have a tripod to hold the camera for a time exposure, and the aperture can be opened up to $\frac{f}{2.8}$. What would be a good exposure time to try? (note: see corrections in December 1983 letter)

11 October 1983 [10]

11.1 Problem 28: Building A Mountain With Rocks

If the energy equal to the annual U.S. electrical energy output (in 1980s) could be used for hoisting rocks, how big of a mountain could be built?

11.2 Problem 29: The Upper Limit On The Rest Mass Of The Photon

Measurements by Pioneer 10 of the magnetic field of Jupiter [25] showed that the range of the electromagnetic force must be at least $5x10^{10}$ cm. How large is the implied upper bound on the rest mass of the photon? If a green photon races an x-ray photon across the visible universe, how far behind will it finish?

11.3 Problem 30: Throwing A Basketball Off A Building

A basketball thrown from the top of a tall building lands on the street below. How high will it bounce?

12 November 1983 [11]

12.1 Problem 31: Can A Light Bulb Emit A Mole Of Photons

The carton containing a $50-$watt light bulb promises an output of 900 lumens and a life of 750 hours. Is this bulb destined to emit as much as one mole of photons during its life?

12.2 Problem 32: Entropy Increase Of Coffee And Milk

When you put cream in your coffee, which causes the larger increase in entropy, the mixing of cream and water or the heat exchange between cream and water?

12.3 Problem 33: Energy In Ocean Waves Compared To Energy From The Sun

In order of magnitude, the energy stored in ocean waves is as much as the Earth receives from the sun in what length of time?

13   December 1983 [12]

13.1 Problem 34: Lifting A Snowflake With A Permanent Magnet

Could a snowflake cooled to 10 microkelvin be lifted with an ordinary permanent magnet acting on the induced nuclear polarization?

13.2 Problem 35: Will Your Breath Recycle Nitrogen

Is it likely or unlikely that your next breath will contain an atom of nitrogen that was in your first breath?

13.3 Problem 36: Power Dissipated By Tidal Friction In Moon's Orbit Receding

If the moon is receding from the Earth at the rate of 4 centimeters per year, how much power is being dissipated in tidal friction?

14   January 1984 [13]

14.1 Problem 37: Spinning A Water Drop

How fast can a $10-$milligram water drop spin without flying apart? (Order of magnitude estimate only; aerodynamic forces to be ignored).

14.2 Problem 38: Refining Aluminum From The Energy In A Power Line

If the energy transmitted by a $100-$kilovolt power line 50 kilometers long is used to refine aluminum, about how long will it take to produce an amount of aluminum equal to that in the cables - an hour, a day, a week, a month, or a year?

14.3 Problem 39: Deflection Of A Light Ray Grazing A Neutron Star

How large, in order of magnitude, is the deflection of a light ray that grazes a neutron star? That grazes a galaxy?

15   February 1984 [14]

15.1   Problem 40: Electromagnetic Energy In Your Eyes

Electromagnetic energy inside your eyeball consists ordinarily of two components: (a) 310 K blackbody radiation and (b) visible photons that have entered through the pupil. In order of magnitude, what is the ratio of the total energy in the second form to that in the first when you have your eyes open in a well-lighted room?

15.2   Problem 41: Oil Carried By A Ribbon

A ribbon 2 cm wide is drawn at a constant speed of $10\frac{cm}{s}$ into a vat of oil and then vertically out of it. The density of the oil is $0.8\frac{g}{cm^3}$ and its viscosity is 0.15 poise ($\frac{dyn*s}{cm^2}$), or $0.015 Pa*s$ ($\frac{N*s}{m^2}$). Estimate the rate at which oil is being carried away by the ribbon.

15.3   Problem 42: Covering The Earth In Paper

Would all the paper ever manufactured suffice to cover the land areas of the Earth?

16   March 1984 [15]

16.1   Problem 43: Energy Equivalent Of A Light Bulb In Barrels Of Oil

A $60-$watt bulb lit for a year takes how many barrels of oil? (Suggested by R. K. Wangsness)

16.2   Problem 44: Track Of All Vehicles On Earth

The total track of all vehicles on Earth lengthens how rapidly?

16.3   Problem 45: How Far We Would See On A Flat Earth (AB Note: Earth Is Flat BTW)

Rayleigh scattering would limit how far we could see horizontally even if the Earth were flat (AB note: I don't know why Purcell phrases this as if the Earth is supposed to be round or something). Estimate the limit, given that liquid nitrogen has a refractive index of 1.2 for visible light and a density of $0.8\frac{g}{cm^3}$.

17   April 1984 [16]

17.1   Problem 46: Estimating The Mean Density Of The Moon

The ratio of the effect of the moon on ocean tides to the effect of the sun is approximately $\frac{7}{3}$. Using that fact and anything you have observed with your eyes, find the ratio of the

mean density of the moon to that of the sun. (Suggested by David F¿ Bartlett).

17.2 Problem 47: Estimating How Much Air Supplies A Person's Daily Oxygen Requirements

If a person when breathing were perfectly efficient at extracting oxygen from the air, how much air would supply the person's daily requirement of oxygen? (Suggested by Ralph Baierlein)

17.3 Problem 48: Stellar Collision Of Two Galaxies

Imagine a galaxy which contains 10^11 stars about like the sun, more or less evenly distributed within a sphere of radius $50,000$ light-years. This galaxy collides head on with a similar galaxy toward which it had been moving at a speed of $300\frac{km}{s}$. How amny stellar collisions are to be expected? (Suggested by Daniel Wilkins)

18 May 1984 [17]

18.1 Problem 49: Changing The Length Of A Day

If every car and truck in the U.S. were driven 300 miles north and left there, how much would the length of a day be changed? (A variation of a problem suggested by Peter Ugincius).

18.2 Problem 50: Emission Of A UV Photon From An Atom

In the near-perfect interstellar vacuum a proton has captured an electron in a circular orbit of $1-$micrometer radius. How soon will this atom emit an ultraviolet photon?

18.3 ✓✓✓ Problem 51: How Cold It Gets When The Sun Turns Off ✓✓✓

Given that the temperature in the Earth's crust increases at the rate of $20\,°C$ per kilometer of depth, how cold would the Earth become with the Sun turned off?

19 June 1984 [18]

19.1 Problem 52: Convex Path Of The Moon

What fraction of the moon's path about the sun is convex toward the sun? (Suggested by Gerhard L. Salinger)

19.2 Problem 53: Energy Released By A Burning Candle

If all the energy released by a burning candle were emitted as 5500 Angstrom photons, how many candle-years of illumination would a $150-$gram candle provide?

19.3 Problem 54: Divergence Of Two Protons

A hydrogen molecular ion, H_2^+, accelerated to 1 MeV, passes through a metal foil 100 Angstroms thick. Its only electron is thereby stripped off without significantly slowing the nuclei. By roughly how large an angle will the subsequent trajectories of the two protons diverge?

20 July 1984 [19]

20.1 Problem 55: Acceleration Due To Gravity At The Gold Nucleus

Is "g" at the surface of a gold nucleus greater or less than $980\frac{cm}{s^2}$?

20.2 Problem 56: Diameter Equivalent Of Your Car's Fuel

If the fuel your car uses were represented by a cylindrical column laid out all along its route, what would be the diameter of that column?

20.3 Problem 57: Pump Power Required To Operate A Human Heart

Given that the heart of a resting person pumps about 75 gallons of blood per hour at a systolic pressure of 120 Torr, estimate the minimum pump power required, in watts

21 August 1987 [20]

21.1 Problem 58: Likelihood Of Hydrogen Collisions In An Interstellar Gas Cloud

A typical interstellar gas cloud may contain 20 hydrogen atoms per cm^3, with a velocity distribution appropriate to a temperature of 100 K. How often does a particular H atom collide with another H atom?

21.2 Problem 59: Sinking A Steel Bearing Ball In The Ocean

How long will it take a $\frac{1}{2}-$inch diameter steel bearing ball to sink one mile in the ocean?

21.3 Problem 60: Richter Magnitude Of A One-Megaton Earthquake

If M is the magnitude of an earthquake on the Richter scale, the total strain energy E released, in joules, is believed to be related to M as follows[26]: $log_{10}E = 2.4 \times M - 1.2$. What is the magnitude of a "one-megaton" earthquake? Describe an event of Richter magnitude $M = 1$.

22 December 1987 [21]

22.1 ✓✓✓ Problem 61: Reading A License Plate With The Hubble Space Telescope ✓✓✓

The new Hubble Space Telescope will have a mirror of 2.4 m diameter. Using it, with no air in the way, how far away could you read a license plate?

22.2 Problem 62: Escape Height Of A Nitrogen Molecule

Let's define "the top of the atmosphere" as the height at which a nitrogen molecule moving upward with more than escape velocity has a probability 0.5 of leaving the Earth for good. About how high is that?

22.3 Problem 63: Reversal Of Earth's Magnetic Field

Suppose that a reversal of the Earth's magnetic field, starting now, is completed in 10^4 years. The equatorial line integral of e during that time will be about how many milli-volts?

22.4 Notes About The December 1987 Edition Of The Back Of The Envelope

The problems that should be found in the December 1987 edition of The Back of The Envelope are not found in a published edition of the American Journal of Physics. I am not sure why this is - it does not appear in the journal as far as I can tell. However, the phrasing and solutions for these problems that would have been found in the December 1987 edition of the Back Of The Envelope are actually found in the January 1988 edition instead.

23 January 1988 [21]

23.1 Problem 64: Lifting A Capacitor Using Its Electrical Energy

In a catalog we find listed a Mylar high-voltage capacitor, capacitance $0.3\mu F$, voltage rating 10 kV DC, the dimensions of which are given, in inches, as $3.25 \times 5.5 \times 2.25$. Estimate

the height to which such a capacitor could be lifted, using all the electrical energy it can store.

23.2   Problem 65: U.S. Food Consumption Expressed As Energy In Fuel

Estimate for the U.S. the ratio of energy consumed in food to energy consumed in fuel

23.3   Problem 66: Storing A Gigabyte In Strings

Bits could be stored as knots in a string, with one orientation of the knot representing 1 and the other representing 0. How much string would you need to store a gigabyte, that is, 8×10^9 bits? (That is, roughly the amount of information in the human genome; see Problem 2 for July 1983)

24   February 1988 [22]

24.1   Problem 67: Comparing The Thermal And Gravitational Energy Of The Earth

Which is larger in absolute magnitude, the thermal energy of matter in the Earth or the (negative) gravitational self-energy of the Earth?

24.2   Problem 68: Opacity Of Dark Mass Made Physical In Space

Imagine that the part of the "dark" mass in the Universe consists of solid grains, each of volume 10^{-3}cm^3 and density $1 \frac{g}{cm^3}$, uniformly distributed so as to raise the mean local density in intergalactic space to $10^{-30} \frac{g}{cm^3}$. Would the resulting opacity of space be detectable? How many such grains would the Earth encounter daily?

24.3   Problem 69: Using Starlight To Light A Sports Event

If all the starlight falling on the State of New York could be directed into Yankee Stadium, would there be enough light for a night game?

25   March 1988 [23]

25.1   Problem 70: Temperature And Quantity Of Argon And Radiation In An Enclosure

An enclosure at the temperature T contains argon and radiation. The partial pressure of each of the two components is 1 Torr. What is the temperature? Is the number of photons enclosed much greater than, approximately equal to, exactly equal to, or much less than, the number of argon atoms?

25.2   Problem 71: Car Combustion Generation

How long does it take a car to generate its own volume of gaseous combustion products? (Suggested by Frank Stein)

26   April 1988 [24]

26.1   Problem 72: Throwing A Baseball Out Of A Spacecraft

From a spacecraft orbiting 200 km above the Earth where the atmospheric density and scale height are, respectively, $4 \times 10^{-10} \frac{kg}{m^3}$ and 50 km, a baseball is tossed out. How long will it last?

26.2   Problem 73: Angular Velocity Of A Rotating Iron Wire

An iron wire 3 cm long and 1 mm in diameter, suspended with its axis vertical, and free to rotate about that axis, is suddenly magnetized by a field parallel to its axis. How large is the resulting increment in its angular velocity?

26.3   Problem 74: Energy Comparison Of Solar System Exit And Human Life

Which is greater, the least energy required to remove a person from the Solar System, or the energy required to feed the person for life?

26.4   Notes About The April 1988 Edition Of The Back Of The Envelope

The problems that should be found in the April 1988 edition of The Back of The Envelope are not found in a published edition of the American Journal of Physics. The phrasing and solutions for these problems that would have been found in the April 1988 edition of the Back Of The Envelope are actually found in the May 1988 edition instead.

27   May 1988 [24]

27.1   Problem 75: Channel Width Of A Planet Full Of AIP Subscribers

Our distant neighbors on Planet X want to subscribe to all the publications of the American Institute of Physics. A channel dedicated to that will have to be how wide?

27.2   Problem 76: Timescale For Temperature Decrease Of The Oceans

With the Sun turned off, how long would it take for the mean temperature of the oceans to fall by $1\,^\circ$C?

27.3 Problem 77: Neutrino Flux Through Your Body From A Supernova

Supernova 1987 A, about $200,000$ light years from the Earth, is estimated to have emitted some 10^{53} ergs in neutrinos of several mega-electron-volts energy. If so, how many of those neutrinos passed through your body?

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