# PHYSICS
# Questions and Answers

ROBIN MARSHALL

Champagne Cat

First published in Great Britain in 2012 by Champagne Cat



A CIP catalogue record for this book
is available from the British library.

ISBN 978-0-9572778-0-9

A Champagne Cat Production

# CONTENTS

# ILLUSTRATIONS

# Front Matter

This is not a standard Introduction, nor an author's Forward. As I typed up the markup language, it came under the category "Front Matter" and given the nature of this book, that seemed a good name to give this section: "Front Matter". More to the point, producing an electronic book myself, I am not encumbered by an editor let alone a sub editor. I am responsible for all sins within and to be honest, I am pleased by that. It is just like being in the lecture theatre, without a pairing twin making a report on me.

A sub editor would probably forbid boxes round headers, but because I can do what I like, curbed only by common sense, I am going to use boxes, because they highlight transitions. I appeal to all true physicists that this cannot be a bad thing. I might even use a double box if I feel like it.

This Front Matter will tell you about the origins of this book and some of the philosophy concerning it. It is of passing interest only. Firstly, I present the version history. I only deal in first heirarchy version numbers, V1, V2, V3 etc. I am not out to derive income by making minor corrections to a version where the minor corrections have been instigated by readers. If you buy any version, you get all subsequent versions for free.

## Origins

When I returned to university as a professor, some 25 years after leaving as a postdoctoral research assistant, I soon realised that I had forgotten most of the basic physics that I had not even understood at the time. I also realised as I took on lecture courses, set examination questions and more important, worked out the answers, that I had never really known how to answer examination questions as a student. I had been taught physics, but not how to approach examination questions. I resolved to put this right. Most physics departments are segmented along the lines of research: particle, nuclear, condensed matter, laser, theoretical, astronomy etc. and there are few physicists around who believe they are only capable of lecturing on their own sub-subject of physics. I further resolved that wherever and as far as possible, I would try to know more about a colleague's sub-field than he or she did about mine, with the possible exception of theoretical particle physics.

There is no single prototype physics exam question setter: they all have their own specialities and peculiarities. But degree exam questions are vetted by a small committee in most progressive universities and it is the purpose of the committee to iron out any inconsistencies and ideosyncrasies. Any erratic behaviour by maverick examiners in the marking stage is largely thwarted by cross checks on the marking scheme by independent colleagues, some of whom are motivated by a desire to find that the "Prof" has bungled. Anything you read here is pretty well down the centre of the road except perhaps for the section on Applied Nuclear Physics where some of the questions are actually course assessments where I had independence, rather than exam questions where strict control was imposed.

**Purpose**

What are the aims and objectives of this tomelet? I know some former departmental colleagues who are implacably opposed to publishing things like this because they fear that some students will use it as a crib sheet to answer intra semester assignments. This argument would have impact if assignment questions were cribbed from my crib sheet. I have reworded most of these questions and re-cast them in fresh language, if only to avoid copyright issues. Physics itself cannot be copyrighted and so all you have to do is to present physics in your own words and there is no question of intellectual property. To the best of my knowledge, Einstein did not register a trademark for $E = mc^2$.

In an ideal world, a student would take these questions one at a time, try to solve them and only if they should find themselves in a state of intellectual desperation, turn to the answer for help. After solving the problem themselves, I hope they will take a look at my answer. There may be a sentence of further enlightenment in my solution – I have tried to include extra physics gossip where possible – or I might even be wrong, in which I have provided my e-mail address and I would welcome a proud joyful message telling me the truth.

My personal experience is that I learnt most physics by reading and re-reading text books on the subject and also by working through problems. This is why this collection of questions and answers exists.

I was torn between the layout I used here and separating questions and solutions into two halves of the book. This would put the solution out of the eye-line and I invite comments on this.

## Version History

V1: 1995. The web had been around for 3 years and I decided to try and use it to get my lecture material to students in the new way. But delivery by web in 1995 was not immediately feasible because only a handful of students had access to it during the vacations. So I provided backup to my lecture course "Gases, Liquids and Solids" in the form of an interactive CD. From 1995 to 2000, I polled students in my class to check how many had access to a PC or Mac during the vacations and I plotted the rise form 10% to quasi 100% in this time span. In an attempt to avoid a poor turnout at my last lecture of the course during the penultimate week of December, I pre-warned the class that during the lecture I would tell them what all the exam questions would be and then at the end, hand out the CD of the course. The CD contained questions and answers about the course and was the embryo of this book.

I believe to this day that giving advance warning of what the questions will be about, has no effect whatsoever on the outcome of a physics examination. I even hired the son of a former Soviet physicist (now at Lancaster University) who had decided on an IT career and was glad to make my CD interactive and even help to write the disks. In the 1990s, economic disk burning technology required about 10 minutes per CD and the CD blanks themselves were not cheap. Six students begged and pleaded with me that they could not attend my final lecture because Pater and Mater had ordered them to go skiing in the Swiss Alps, on pain of disinheritance. Therefore, could I please slip them an advance copy of the CD so they would not be at a disadvantage. I feigned reluctance, but was glad to oblige. And it saved my bacon.

The first that I knew that "Trouble was up" was when the phone call came in from Zermatt: "Your disk has a virus". He was right. Goodness knows what the former Soviet IT whizz kid is doing now, but his master disk encapsulated the classic "Chernobyl" virus, which was a ticking nuclear time bomb, poised to wreck more than 200 students' PCs.

Five further difficult phone calls later, with 200 expensive, freshly burnt but useless disks binned and groveling promises from me on the telephone that I would DHL a replacement clean disk to Zermatt, the Former Soviet's son IT whizz Kid produced a clean master disk. It was a natural safe extension to create a questions and answers file on a separate, non interactive and safe CD and here is the result.

V2: 1997. More subject topics added.
V3: 2000. Applied Nuclear questions added.
V4: 2005. Clean up.
V5: 2008. Re-typeset using TeXShop, when it finally became clear that Textures would never make it to OSX.
V6: 2012. First edition prepared for electronic publication.

**Access to future versions**

If you buy this version, all future versions in this electronic format will be provided free.

## Errors and omissions

It is possible that there are physics text books that have no errors. I would expect that those by my former tutor Franz Mandl might fall into this category. But I am not Franz Mandl and I urge you to use these notes as a general guidance on how to go about your exams. If I have made an error, I apologise. It should not cost you a degree class unless you use these notes in a way not intended, which is to memorise and copy. Surely few of you can do this. Follow the main road but take your own sideways diversions now and then.

## Feedback

I welcome any feedback and will respond to most polite comments and questions.

You can e-mail me at R.Marshall@manchester.ac.uk

# I. The Method of Dimensional Analysis

The notation I will use here, is to denote the dimension of a quantity by [ ].

The procedure to answer this type of question is firstly to write out the dependence in a generic fashion thus:

$$y = w^a x^b z^c$$

Here $y$ will be a physical observable (e.g. rate of flow of a liquid) which depends on possible other physical observables $w$, $x$ and $z$, which in turn have units that can be expressed in terms of the basic units of mass, $M$, length $L$ and time $T$. There can, of course, be more than or less than three physical observables.

Then secondly, by equating the powers of $M$, $L$ and $T$, this leads to a set of simultaneous equations which can be solved for $a$, $b$ and $c$.

It is a rather obvious statement that it is difficult to proceed if you do not know the dimensions of any of the quantities $y$, $w$, $x$ and $z$. However, it is not necessarily a complete show-stopper. First try to make an intelligent deduction. If that doesn't get you far, then make an honest guess. You may guess right and at least you will get credit for correctly working out the dependence that follows from this wrong guess. You should (if I were marking) get slightly more credit for stating honestly that you don't know but are making an intelligent guess, than if you try to bluster through with yards of woffle.

**Method of Dimensions: Question 1.***

By means of dimensional analysis, show how the rate of flow of volume of liquid through a long tube depends on the pressure gradient, the viscosity of the liquid and the diameter of the tube. Any other dependences can be ignored.

**Solution:**

We want to find $a$, $b$ and $c$ in the following equation:

$$\frac{\mathrm{d}V}{\mathrm{d}t} = \left(\frac{\mathrm{d}P}{\mathrm{d}x}\right)^a \eta^b d^c$$

$V$ is the volume, $\frac{\mathrm{d}V}{\mathrm{d}t}$ the volume flow, $\eta$ is the viscosity, $P$ is the pressure and $\frac{\mathrm{d}P}{\mathrm{d}x}$ the pressure gradient.

So

[volume flow] = $[\mathrm{d}V/\mathrm{d}t] = L^3T^{-1}$
[pressure gradient] = $[\mathrm{d}P/\mathrm{d}x] = ML^{-2}T^{-2}$
[viscosity] = $[\eta] = ML^{-1}T^{-1}$
[diameter] = $[d] = L$

We start by setting up the dimensional equation:

$$L^3\, T^{-1} = \left(M\, L^{-2}\, T^{-2}\right)^a \left(M\, L^{-1}\, T^{-1}\right)^b (L)^c$$

$$
\begin{array}{lrcll}
M \text{ coefficient} & 0 & = & a + b & (1) \\
L \text{ coefficient} & 3 & = & -2a - b + c & (2) \\
T \text{ coefficient} & -1 & = & -2a - b & (3) \\
(2) - (3) & c & = & 4 & \\
(1) + (3) & a & = & 1 & \\
(1) \quad \text{gives} & b & = & -1 &
\end{array}
$$

And the final answer can be written out in full:

$$\frac{\mathrm{d}V}{\mathrm{d}t} = \frac{\mathrm{d}P}{\mathrm{d}x}\eta^{-1}d^4$$

Perhaps the most difficult part of this question would be recalling the dimensions of viscosity. Knowing an alternative equation containing $\eta$ would help and I leave it to the reader to find one, then it might stick.

**Method of Dimensions: Question 2.***

Use dimensional arguments to show that the speed of waves on a deep volume of liquid is independent of the liquid density if the waves are long enough to be controlled by gravity, but not if they are short enough to be controlled by surface tension.

**Solution:**

This question uses deep water surface waves as a vehicle to test your skills in dimensional analysis. It might help to answer the question if you know the two types of surface wave:

- long wavelength: gravity waves, controlled by gravity
- short wavelength: capillary waves, controlled by surface tension

Case 1: Gravity waves: We want to determine the form of the dispersion relation: $\omega = \omega(k)$ where $\omega$ is (angular) frequency and $k$ the wave number. This equation then allows the speed to be obtained.

We might *a priori* expect $\omega$ to depend on the liquid density $\rho$, the acceleration due to gravity $g$ and the wave number $k$. Taking a hint from the question, let us leave out surface tension here, but after looking at the second half of the question, you could go back and try this bit again with surface tension in and see what happens.

So, setting up the dimension equalities:

$$\begin{aligned}
[\omega] &= T^{-1} = [\rho]^a [g]^b [k]^c \\
[\rho] &= ML^{-3} \\
[g] &= LT^{-2} \\
[k] &= L^{-1}
\end{aligned}$$

$$\begin{aligned}
\text{Substituting :} \qquad [\omega] &= T^{-1} = M^a L^{-3a+b-c} T^{-2b} \\
\text{And then :} \qquad a &= 0 \qquad (1) \\
b &= 1/2 \qquad (2) \\
-3a + b - c &= 0 \qquad (3)
\end{aligned}$$

Equation (1) shows that there is no $\rho$ dependence (i.e. $\omega \sim \rho^0$).

Also $b = c = 1/2$. And although not asked for, for completeness: $\omega = A\sqrt{gk}$, where $A$ is a constant.

Case 2: Capillary waves: Proceed as for case 1) but now include the extra dependent variable $\sigma$, the surface tension. Now $\omega = \omega(\sigma, \rho, g, k)$. The extra dimension for this case, compared to case 1) is: $[\sigma] = MT^{-2}$.

So:

$$\begin{aligned}
[\omega] &= T^{-1} = [\rho]^a [g]^b [k]^c [\sigma]^d \\
&= M^{a+d} L^{-3a+b-c} T^{-2b-2d} \\
a + d &= 0 \\
-3a + b + c &= 0 \\
b + d &= 1/2
\end{aligned}$$

At first sight, it seems difficult if not impossible to proceed because there are only 3 equations for 4 unknowns. The next question (Q3) and its solution shows how to proceed in general when faced with this seemingly insoluble problem. It is only a problem mathematically and physics can overcome it. In this question we are not asked to perform a full dimensional analysis, but rather to simply answer a specific question and show that $a \neq 0$ in this special case.

It just needs the application of a bit of logic:

Let us see what happens if we assume the contrary, i.e. assume that $a = 0$. Then $d$ must also $= 0$, because $a + d = 0$. But if $d = 0$ then $\omega$ does not depend on $\sigma$, whereas we are told that it does. Therefore the assumption that $a = 0$ leads to a contradiction and hence $a \neq 0$. Thus $\omega$ depends on $\rho$ and we can even say: $\omega \sim \rho^a$.

This is often a useful ploy in physics. To prove that something is true, assume that it isn't true and show that such an assumption inevitably leads to a contradiction.