Invitation

Acceleration - Advanced Physics Coaching

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January 16, 2022

1 Introduction

Why are snowflakes hexagonal? What happens to the water level in a cup after an ice cube melts? How high could the tallest mountain on Mars be?

The study of physics, at its very core, is asking and answering questions like this. From my teaching experience, students, independent of knowledge and proficiency level, are similarly curious to understand the world around them. Some students then take off and breeze through problems with the slightest external guidance, while some stumble at making the leap in problem-solving.

Here's the bottom line: I don't know what your current aptitude in physics or your impression of the subject is, but I can claim with certainty, that with the right push, every student can be taught to appreciate and excel in physics in their own ways.

The aim of this course is, as the title of this document states, to study physics at a high level. That said, the definition of "high level" is a vague one. Whether you are an IP student aiming for a consistent grade point of 4.0, a H3 candidate looking to secure a Distinction on your A-Level certificate, an aspiring Physics Olympiad medallist, or just a curious learner interested to explore the subject at a deeper level, you will find the appeal in this course.

Majority of the material are put together through my personal encounters and contemplations about each individual topic, with the hope of articulating advanced thoeries in an intuitive manner, overturning any pre-existing misconceptions, and helping you independently develop problem-solving skills to algorithmically tackle complex problems.

2 Course Outline

If you haven't figured out by now, the course name is **Acceleration**! Lessons are targeted for the development of the following two skills: intuition (understanding), and rigor (practice). Details are outlined below:

- Duration: 2 hours per lesson (exact time to be determined, but should be on a weekend afternoon/evening!)
- Frequency: once a week
- Format: Lecture + Practice problem set + In-class discussion
- Location: Online (Zoom)

Sample problems are attached at the end of this document for your reference.

3 Contact

You can find me at any of the following contacts:

- Whatsapp/Telegram/WeChat: +65 92329069
- Email: fuxinghong1@gmail.com
- Alternatively, you can indicate your interest with the following sign-up form https://forms.gle/UGN3EfSnqBLASXK39

Let me know if you are keen to join us, if you need any clarifications, or if you have any questions on physics or school life in general! I look forward to working with you!

Best,
Fu Xinghong
Singapore Physics Olympiad National Team Trainer
International Physics Olympiad Gold Medallist
International Young Physicist Tournament Champion

4 Sample Problems

Part A problems are hands-on application problems for students to practice directly applying the concepts and formulas to mathematically understand simple physical scenarios.

Problem A.1. Throwing stones

At the top of a cliff of height 100m, a boy throws a stone vertically upwards at a velocity of 15ms^{-1}. How much time later should he drop a second stone from rest such that both stones reach the bottom of the cliff at the same time?

Intermediate problems like those in Part B tend to be more subtle, but these are the ones, when practiced in bulk, develop physical intuition and a tighter grasp on the abstract formulas and equations.

Problem B.1. Rolling off

A solid sphere of radius r is initially placed at rest on top of a fixed hemisphere, also of radius r. The solid sphere is then given a slight push and begins rolling down the hemisphere. At what angle θ from the vertical will the sphere lose contact with the hemisphere? Assume the sphere always rolls without slipping.

Here in Part C you should find the most conceptually complex and mathematically intensive problems, but you should still savour the process of carefully thinking through questions like this, for this is the essence which makes problem-solving in physics enjoyable. And don't forget to give yourself a pat on the back after solving these!

Problem C.1. The rotating saddle

A particle of mass m can move in the plane (x, y) and experiences a conservative force corresponding to the potential:

$$U(x, y) = \frac{1}{2}m\omega^2(x^2 - y^2). \tag{1}$$

See this link for a demonstration of the problem.

(a) Show that there exists one and only one equilibrium position for the particle. Is it stable?

(b) One rotates the system around the z-axis, with angular velocity Ω. Write down the equations of motion in the rotating frame.

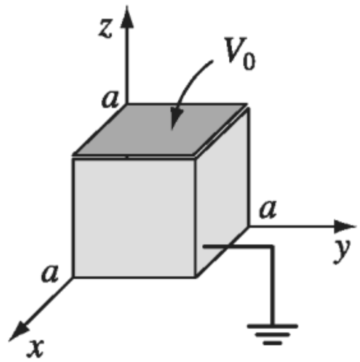
Note: In the rotating frame, a particle of mass m at position $\vec{r}$ with velocity $\vec{v}$ experiences a centrifugal force of $\vec{F}_{centri} = -m\vec{\Omega} \times (\vec{\Omega} \times \vec{r})$ and a Coriolis force $\vec{F}_{cor} = -2m\vec{\Omega} \times \vec{v}$.

(c) Make the subsitution $x = x_0 e^{rt}$ and $y = y_0 e^{rt}$ and show that a non-trivial solution, *i.e.* $(x_0, y_0) \neq (0, 0)$, exists if and only if $r^4 + 2\Omega^2 r^2 + \Omega^4 - \omega^4 = 0$.

(d) For which values of Ω can the particle be trapped?
(e) For a saddle of shape $z = (x^2 - y^2)/R$ with $R = 0.45$m, what is the critical frequency f for stabilization of the ball placed on the saddle?

**Bonus Part D problems span a variety: from quick brain teasers (like those found at the start of Section 1) to challenging ones employing even more advanced techniques than those found in Part C. They are usually out of the scope of even the most accelerated high school curriculums, and will likely not be tested for olympiads either. But nonetheless, here's one such problem to keep you entertained if you are done with all the above problems.*

Problem D.1. Cubic potential



In the figure above, a cubical box (sides of length a) consists of five metal plates, which are welded together and grounded. The top is made of a separate sheet of metal, insulated from the others, and held at a constant potential V_0.
(a) Find the potential distribution $V(x, y, z)$ inside the box.
(b) What is the potential at the center $(a/2, a/2, a/2)$ of the box? Is there a way to obtain this answer without calculating the entire potential distribution?