The Southern California Physics GRE Bootcamp

Held at CSU Long Beach, August 23-24, 2013

Damien Martin
### Total Score

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*Percentage scoring below the scaled score is based on the performance of 11,322 examinees who took the Physics Test between October 1, 1993, and September 30, 1996.*

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**Question Answers**

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(35) 20-35 percentile

(18) <20 percentile
Big tips and tricks

* Multiple passes through the exam

* Dimensional analysis (which answers make sense?)
  Other hint -- look at exponentials, sines, cosines, ...

* Expansions, in particular $(1+x)^n = 1 + nx + ........$

* Limiting cases (e.g. make parameters go to 0 or infinity)

* Special cases (e.g. looking at circles)

* Powers of ten estimation

* Know scales of things [wavelength / freq of visible light, binding energies of nuclei, mass ratios of common particles (up to muon, pion), ...., mass of stars, mass of galaxies, ....]

Okay to specialize on scales
Big tips and tricks -- material

* Know your “first year” general physics really well
  - Newtonian mechanics in particular

* Worth going through
  Griffiths: Intro to electromagnetism
  Griffiths: Intro to quantum mechanics
  (Concentrate on harmonic osc, infinite square well, spin systems)
  Schroeder: Thermal physics

* Look at the archive of monthly problems in The Physics Teacher (if you have access to a university library)
Evaluate whether question is “special” or “first year”
\[ C = 3kN_A \left( \frac{hv}{kT} \right)^2 \frac{e^{hv/kT}}{(e^{hv/kT} - 1)^2} \]

65. Einstein’s formula for the molar heat capacity \( C \) of solids is given above. At high temperatures, \( C \) approaches which of the following?

(A) 0
(B) \( 3kN_A \left( \frac{hv}{kT} \right) \)
(C) \( 3kN_A hv \)
(D) \( 3kN_A \)
(E) \( N_A hv \)
65. Einstein’s formula for the molar heat capacity $C$ of solids is given above. At high temperatures, $C$ approaches which of the following?

(A) 0

(B) $3kN_A \left( \frac{hv}{kT} \right)$

(C) $3kN_A hv$

(D) $3kN_A$

(E) $N_A hv$

Call $x = \frac{hv}{kT}$

$$C = 3kN_A x^2 \frac{e^x}{(e^x - 1)^2}$$

$$= 3kN_a x^2 \left[ \frac{1 + x + \ldots}{(1 + x + \ldots - 1)^2} \right]$$

$$= 3kN_a x^2 \left[ \frac{1}{x^2} + \ldots \right]$$

$$= 3kN_a + \ldots$$
8. A particle of mass $m$ undergoes harmonic oscillation with period $T_0$. A force $f$ proportional to the speed $v$ of the particle, $f = -bv$, is introduced. If the particle continues to oscillate, the period with $f$ acting is

(A) larger than $T_0$
(B) smaller than $T_0$
(C) independent of $b$
(D) dependent linearly on $b$
(E) constantly changing
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(A) larger than $T_0$
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(D) dependent linearly on $b$
(E) constantly changing

Generalize lessons!

$$F = m\ddot{x} = -kx - b\dot{x} \Rightarrow \ddot{x} + \frac{b}{m} \dot{x} + \frac{k}{m} x = 0$$

Can solve exactly -- but wrong approach.

Different competing effects -- which wins?

Appeal to (J)WKB, approximation schemes, etc...
Things to know (they always seem to come up)

1) Elastic collision formula
Things to know (they always seem to come up)

1) Elastic collision formula

\[ v_{1f} = \frac{m_1 - m_2}{m_1 + m_2} v_0 \]

\[ v_{2f} = \frac{2m_1}{m_1 + m_2} v_0 \]
Things to know (they always seem to come up)

1) Elastic collision formula

Before collision

\[ v_{1f} = \frac{m_1 - m_2}{m_1 + m_2} v_0 \]

\[ v_{2f} = \frac{2m_1}{m_1 + m_2} v_0 \]

After collision

2) The limiting behavior of capacitors and inductors in DC

acts like (while uncharged)

(while fully charged)

(e.g. high pass filter question)
3) Virial theorem (and the quick way to get it)

$m$ is reduced mass!
(To get levels for e.g. positronium, same formula but use reduced mass for that system)
3) Virial theorem (and the quick way to get it)

\[ F(r) = Ar^n \Rightarrow V = \frac{A}{1+n} r^{1+n} = \frac{F(r)}{1+n} r \]

\[ \frac{mv^2}{r} = F(r) \Rightarrow \frac{1}{2} mv^2 = \frac{1}{2} F(r) r \]

\( m \) is reduced mass!

(To get levels for e.g. positronium, same formula but use reduced mass for that system)
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\[ F(r) = Ar^{-n} \Rightarrow V = \frac{A}{1 + n} r^{1+n} = \frac{F(r)}{1 + n} r \]

\[ \frac{mv^2}{r} = F(r) \Rightarrow \frac{1}{2} mv^2 = \frac{1}{2} F(r) r \]

\[ \langle KE \rangle = \frac{1 + n}{2} \langle V \rangle \]

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\[ \langle KE \rangle = \frac{1+n}{2} \langle V \rangle \]

4) The Bohr formula (or know how to get it quickly)

\[ E = -\frac{Z^2(k_e^2)^2 m}{2\hbar^2 n^2} \]

\( m \) is reduced mass!

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\[ F(r) = Ar^+n \Rightarrow V = \frac{A}{1+n}r^{1+n} = \frac{F(r)}{1+n}r \]

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\( m \) is reduced mass!

(To get levels for e.g. positronium, same formula but use reduced mass for that system)

5) Combining masses, springs, capacitors, resistors

Can you find \( k_{\text{equiv}} \)?
Frequency of oscillation?
Know reduced mass!
7. As shown above, a ball of mass $m$, suspended on the end of a wire, is released from height $h$ and collides elastically, when it is at its lowest point, with a block of mass $2m$ at rest on a frictionless surface. After the collision, the ball rises to a final height equal to

(A) $\frac{1}{9} h$
(B) $\frac{1}{8} h$
(C) $\frac{1}{3} h$
(D) $\frac{1}{2} h$
(E) $\frac{2}{3} h$

Apply elastic collision equations!
49. The infinite xy-plane is a nonconducting surface, with surface charge density $\sigma$, as measured by an observer at rest on the surface. A second observer moves with velocity $v \hat{x}$ relative to the surface, at height $h$ above it. Which of the following expressions gives the electric field measured by this second observer?

(A) $\frac{\sigma}{2\varepsilon_0} \hat{z}$

(B) $\frac{\sigma}{2\varepsilon_0} \sqrt{1 - \frac{v^2}{c^2}} \hat{z}$

(C) $\frac{\sigma}{2\varepsilon_0 \sqrt{1 - \frac{v^2}{c^2}}} \hat{z}$

(D) $\frac{\sigma}{2\varepsilon_0} \left( \sqrt{1 - \frac{v^2}{c^2}} \hat{z} + \frac{v}{c} \hat{x} \right)$

(E) $\frac{\sigma}{2\varepsilon_0} \left( \sqrt{1 - \frac{v^2}{c^2}} \hat{z} - \frac{v}{c} \hat{y} \right)$
Multiple approaches:

• Know how **E** transforms
  (from upper div E&M, F_{ab} transforms as rank-2 tensor)

• Know how **A** transforms
  (4-vector, messy to get E)

• Have a picture of rest frame!
  (Last preferred)
84. Two pendulums are attached to a massless spring, as shown above. The arms of the pendulums are of identical lengths $\ell$, but the pendulum balls have unequal masses $m_1$ and $m_2$. The initial distance between the masses is the equilibrium length of the spring, which has spring constant $K$. What is the highest normal mode frequency of this system?

(A) $\sqrt{g/\ell}$

(B) $\sqrt{K/m_1 + m_2}$

(C) $\sqrt{K/m_1 + K/m_2}$

(D) $\sqrt{g + K/m_1 + K/m_2}$

(E) $\sqrt{2g/\ell + K/m_1 + m_2}$
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(A) $\sqrt{\frac{g}{\ell}}$

(B) $\sqrt{\frac{K}{m_1 + m_2}}$

(C) $\sqrt{\frac{K}{m_1} + \frac{K}{m_2}}$

(D) $\sqrt{\frac{g}{\ell} + \frac{K}{m_1} + \frac{K}{m_2}}$

(E) $\sqrt{\frac{2g}{\ell} + \frac{K}{m_1 + m_2}}$

$\text{Reduced mass}$
What distance from the center of the Earth does a geosynchronous satellite travel at?

What is the emission energy from a photon going from \( n = 3 \) to \( n = 1 \) in positronium (one electron and one positron orbiting one another)?
What distance from the center of the Earth does a geosynchronous satellite travel at?

\[ \frac{GM_E m_s}{R_s^2} = m_s \omega^2 R_s \]
\[ \frac{g R_E^2}{R_s^2} = \omega^2 R_s \]
\[ \frac{GM_R R_E^2}{R_s^2} = \omega^2 R_s \]

What is the emission energy from a photon going from \( n = 3 \) to \( n = 1 \) in positronium (one electron and one positron orbiting one another)?

Rule for Hydrogen like atoms: \( E_n = -\frac{13.6 \text{ eV}}{n^2} Z^2 \)

But 13.6 is proportional to the reduced mass \( m = m_{\text{electron}} \) in Hydrogen

In positronium \( m = m_e / 2 \), so we have to halve the 13.6

\[ E_n = -\frac{6.8 \text{ eV}}{n^2} \]

(positronium energy levels)

\[ E_{\text{photon}} = E_3 - E_1 = 6.8 \text{ eV} \left( \frac{1}{1^2} - \frac{1}{3^2} \right) = 6.8 \text{ eV} \times \frac{8}{9} \approx 6 \text{ eV} \]
Two different ways of connecting a mass $m$ to two identical springs with spring constant $k$ are shown above. If we denote the frequency of oscillation in situation 1 by $f_1$ and the frequency of oscillation in situation 2 by $f_2$ then $f_1/f_2$ is:

a) 4  
b) 2  
c) 1/2  
d) 1/4  
e) depends on $m$ and / or $k$
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a) 4  

b) 2  

c) 1/2  

d) 1/4  

e) depends on $m$ and / or $k$

(Hint: can pretend $k_1$ and $k_2$ are not the same to take limits to determine formula for $k_{eff}$)

\[
\frac{f_1}{f_2} = \frac{\omega_1}{\omega_2} = \sqrt{\frac{k_{eff,1}/m}{k_{eff,2}/m}} = \sqrt{\frac{k_{eff,1}}{k_{eff,2}}} = \sqrt{\frac{2k}{k/2}} = 2
\]
A particle sits in a periodic potential

\[ V(x) = d \sin(kx) \]

What is its oscillation frequency about the minimum?
A particle sits in a periodic potential

\[ V(x) = d \sin(kx) \]

What is its oscillation frequency about the minimum?

Let \( y \) be the distance from the minimum. Expanding about the minimum we have:

\[ V(y) = V_{\text{min}} + 0y + \frac{1}{2} \left. \frac{d^2 V}{dy^2} \right|_{\text{min}} y^2 + \ldots \]

0 (because min) \hspace{1cm} Just a number, not a function

Force is

\[ F = -\frac{dV}{dy} = -\left. \frac{d^2 V}{dy^2} \right|_{\text{min}} y + \ldots \]

SHM with “spring constant” \( k = \frac{d^2 V}{dy^2} \) evaluated at min!

spring constant = \( -dk^2 \sin(kx) = +dk^2 \) evaluated at min

\[ f = 2\pi \sqrt{\frac{\text{spring const.}}{m}} = 2\pi \sqrt{\frac{dk^2}{m}} \]
6) Making problems look like a harmonic oscillator

\[ \omega^2 = \left( \frac{d^2V}{dx^2} \right)|_{\text{min}} \]

\[ \frac{m}{m} \]

7) Remember spectroscopic notation (ugh)

\[ {}^{2s+1}(\text{orbital angular momentum symbol})_j \]

and the selection rules for an electric dipole
8) Know the pattern of spherical harmonics

\[
Y^0_0(\theta, \varphi) = \frac{1}{2} \sqrt{\frac{1}{\pi}}
\]

(\ell = 0)

\[
Y^{-1}_1(\theta, \varphi) = \frac{1}{2} \sqrt{\frac{3}{2\pi}} \sin \theta e^{-i\varphi}
\]

\[
Y^1_1(\theta, \varphi) = \frac{1}{2} \sqrt{\frac{3}{2\pi}} \sin \theta e^{i\varphi}
\]

(\ell = 1)

(But if you can remember these, congratulations)

Too detailed ...... !
8) Know the pattern of spherical harmonics

\[ Y^m_\ell \]  

\( m \) – magnetic quantum number \((-\ell, -\ell + 1, \ldots, \ell)\)

\( \ell \) – orbital quantum number \((0, 1, 2, \ldots)\)

\( Y^m_\ell \) contains \( \varphi \) dependence of the form \( e^{im\phi} \)

\( Y^m_\ell \) contains \( \ell \) dependence of the form \( \sin^\ell \theta, \ \sin^{\ell-1} \theta \cos \theta, \ldots \)

(i.e. can write as \( \ell \) sines or cosines multiplied, or as \( \sin(\ell \theta), \cos(\ell \theta) \).)

Compare these rules to the spherical harmonics listed one slide ago.
Random mechanics problem:

A ball and a block of mass $m$ are moving at the same speed $v$. When they hit the ramp they both travel up it. The block slides up with (approximately) no friction, the ball experiences just enough friction to roll without slipping. Which goes higher?

a) the ball goes higher
b) the black goes higher
c) they go the same height
d) Impossible to tell from information given
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The ball has both translational kinetic energy (equal to that of the block) and rotational kinetic energy. Therefore

$$KE_{ball, initial} > KE_{block, initial}$$

The ball converts all this energy into potential energy, and therefore goes higher.