Lecture 2:
Introduction to Experiment 1

Physics 3719
Spring Semester 2011
Experiment 1: Simple Pendulum

\[ \vec{F} = m \ddot{a} \]
\[ F = m \dot{v} \]
\[ -mg \sin \theta = ml \ddot{\theta} \]

Equation of motion for a simple pendulum:

\[ \ddot{\theta} + \frac{g}{l} \sin \theta = 0 \]

For small angles, \( \sin \theta \approx \theta \), and

\[ \ddot{\theta} + \frac{g}{l} \theta = 0 \]

\[ \rightarrow \text{a simple harmonic oscillator} \]
Experiment 1: Simple Pendulum

**SHO** will have solutions like

\[ \theta(t) = \theta_0 \cos \left( \sqrt{\frac{g}{l}} t \right) \]

the frequency \( \omega \) and period \( T \) of oscillation are

\[ \omega = 2\pi f = \frac{2\pi}{T} = \sqrt{\frac{g}{l}} \]

or

\[ T^2 = 4\pi^2 \frac{l}{g} \]
Experiment 1: Simple Pendulum

SHO will have solutions like

$$\theta(t) = \theta_0 \cos\left(\sqrt{\frac{g}{l}} t\right)$$

the frequency $\omega$ and period $T$ of oscillation are

$$\omega = 2\pi f = \frac{2\pi}{T} = \sqrt{\frac{g}{l}}$$

or

$$T^2 = 4\pi^2 \frac{l}{g}$$
To what precision can we measure $g$?

- For now, just consider measuring a single data point.

- Use **error propagation** equation that we learned in freshman labs.

- Conclusion: Relative uncertainty in **time** has bigger effect than uncertainty in **length**.

Error propagation: If $f = f(a, b, c, \ldots)$ then

$$S_f^2 = \left(\frac{\partial f}{\partial a}\right)^2 S_a^2 + \left(\frac{\partial f}{\partial b}\right)^2 S_b^2 + \left(\frac{\partial f}{\partial c}\right)^2 S_c^2 + \ldots$$

As applied in this case:

$$g = g(l, T) = \frac{4\pi^2 l}{T^2}$$

$$S_g^2 = \left(\frac{\partial g}{\partial l}\right)^2 S_l^2 + \left(\frac{\partial g}{\partial T}\right)^2 S_T^2$$

Which gives us

$$\frac{S_g}{g} = \sqrt{\left(\frac{S_l}{l}\right)^2 + \left(\frac{2S_T}{T}\right)^2}$$
Uncertainty in time

- How can we improve uncertainty in our timing measurements?
Uncertainty in time

- How can we improve uncertainty in our timing measurements? **Averaging**
- What is uncertainty in the average?
Root Mean Square Deviation (RMS)

If I make $N$ measurements of a quantity $x$ then

$$\sigma_x = \sqrt{\frac{1}{N} \sum_{i=1}^{N} (x_i - \bar{x})^2}$$

also called the population standard deviation. This can be thought of as the expected uncertainty in a single measurement.

The uncertainty in the mean is given by (proof left as homework problem):

$$S_{\bar{x}} = \frac{\sigma_x}{\sqrt{N}}$$
Example: Compute mean and RMS for the following data:

<table>
<thead>
<tr>
<th>i</th>
<th>x</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>18</td>
</tr>
<tr>
<td>2</td>
<td>10</td>
</tr>
<tr>
<td>3</td>
<td>12</td>
</tr>
<tr>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>5</td>
<td>9</td>
</tr>
</tbody>
</table>
Uncertainty in length

- Comes from limits on our ability to read tic marks off of ruler.

\[
\frac{S_g}{g} = \sqrt{\left(\frac{S_l}{l}\right)^2 + \left(\frac{2S_T}{T}\right)^2}
\]

- 1% uncertainty → requires 10 cm length
- 0.2% uncertainty → requires 50 cm length
- Ultimately, uncertainty in length will limit the precision of this measurement!
Due Tuesday January 18th
(my noon in my mailbox)

- **One-page** (typed) explanation of your measurement of $g$.
- List equations used, model assumed.
- Describe your technique.
- Describe any calculations you did.
- Report your final answer, with uncertainty.
- Compare your result with previous measurements
Writing Scientific Papers

Somewhere, something went terribly wrong
Motivation

- Measurements or calculations useless unless they are communicated
- Signpost for completion of scientific work
- Real world issues
  - Required for continued support of work
  - Academia: “publish or perish”...
Details

- For each lab this semester, you will write a paper in the form of a scientific article.
- The papers should be done individually, although of course you are sharing data.
- Paper may be written in Word, LaTeX, et cetera. Not by hand!
- No specified length; shoot for ~4 pages
- Due date is Wednesday after the last lab period.
Your papers should include...

- Title and Author
- Abstract
- Section 1: Introduction
- Section 2: Method
- Section 3: Data and Results
- Section 4: Discussion
- Section 5: Conclusion
- References
Abstracts

• Motivate reader to keep going!

• A few sentences describing purpose, technique and major results.

• Sometimes abstract is specifically labeled...

Cosmic rays: the Second Knee and beyond

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Abstract

We conduct a review of experimental results on ultra-high energy cosmic rays (UHECRs) including measurements of the features of the spectrum, the composition of the primary particle flux and the search for anisotropies in event arrival direction. We find that while there is a general consensus on the features in the spectrum—the Second Knee, the Ankle and (to a lesser extent) the GZK Cutoff—there is little consensus on the composition of the primaries that accompany these features. This lack of consensus on the composition makes interpretation of the agreed upon features problematic. There is also little direct evidence about potential sources of UHECRs, as early reports of arrival-direction anisotropies have not been confirmed in independent measurements.

(Some figures in this article are in colour only in the electronic version)

1. Introduction

Ultra-high energy cosmic rays (UHECRs) are the most energetic form of radiation known to hit the earth. At these energies, above $10^{18}$ eV, one would like to understand the workings of the astrophysical accelerators which are able to produce such high energies, energies many orders of magnitude higher than what is available in terrestrial accelerators. These high energy particles also have, perhaps, much to tell us about the regions in which they were accelerated and the vast spaces through which they passed on their way to us. However, before we can understand, we must measure: what is the energy spectrum, what kind of particles are they, where do they come from?

This will be a review of the latest experimental results from which one may hope to understand UHECRs. There has been significant experimental activity since the last experimental review appeared in this journal (Yoshida and Dai 1998), and there has been some movement towards a consensus on the existence and energies of various features in the
Abstracts

- ... and sometimes not.
- Often this is all that will get read!
- Look in the literature for examples.

In 1966, Greisen [1], and Zatsepin and Kuzmin [2], proposed an upper limit to the cosmic-ray energy spectrum. Their predictions were based on the assumption of a proton-dominated extragalactic cosmic-ray flux which would interact with the photons in the cosmic microwave background (CMB) via photo-pion production. From the temperature of the CMB and the mass and width of the $\Delta^0$ resonance, a "Cutoff" threshold of $\sim 6 \times 10^{18}$ eV was calculated, and a suppression in the cosmic-ray flux beyond this energy (commonly called the Cutoff) was predicted. This is a strong energy-loss mechanism that limits the range of cosmic protons above this threshold to less than $\sim 30$ MeV.

Several earlier experiments [3-6] have reported the detection of one event above $10^{20}$ eV. A continuing, unbroken spectrum beyond the predicted Cutoff threshold was later reported by a larger experiment, the Akeno Giant Air Shower Array (AGASA) [7, 8].

The High Resolution Fly's Eye (HiRes) experiment was operated on clear, moonless nights over a period of nine years (1997-2006). During that time, HiRes collected a cumulative exposure more than four times that collected by AGASA above the Cutoff threshold. The HiRes experiment observed cosmic rays by imaging the extensive air shower (EAS) generated by a primary cosmic ray. Ultraviolet fluorescence (UV) light is emitted by nitrogen molecules in the wake of the EAS and collected by our detector.

Forty years after its initial prediction, the HiRes experiment has observed the Cutoff. In this article we describe our measurement of the flux of cosmic rays, the resulting cosmic-ray energy spectrum, our analysis of this spectrum to infer the existence of the cutoff and our estimate of systematic uncertainties.

The HiRes project has been described previously [9, 10]. The experiment consists of two detector stations (HiRes-I and HiRes-II) located on the U.S. Army Dugway Proving Ground in Utah, 12.5 km apart. Each station is composed of telescope modules (22 at HiRes-I and 42 at HiRes-II) pointing at different parts of the sky, covering nearly 360° in azimuth, and 3°−17° (HiRes-I), and 3°−31° (HiRes-II) in elevation. Each telescope module collects and focuses UV light from an air shower using a spherical mirror of 3.7 m² effective area. A cluster of 256 photomultiplier tubes (PMTs) is placed at the focal plane of each mirror and serves as the camera for each telescope. The field of view of each PMT subtends a one degree diagonal cone on the sky.

HiRes data analysis is carried out in two ways. In monocular mode, events from each detector site are selected and reconstructed independently. The combined monocular dataset has the best statistical power and covers the widest energy range. The dataset consisting of events seen by both detectors, data analyzed in stereo mode, has the best resolution, but covers a narrower energy range and has less statistics[11]. This article
Astrophysics

New submissions

Submissions received from Fri 24 Oct 08 to Mon 27 Oct 08, announced Tue, 28 Oct 08

- New submissions
- Cross-lists
- Replacements

[ total of 90 entries: 1-90 ]
[ showing up to 200 entries per page: fewer | more ]

New submissions for Tue, 28 Oct 08

G. Torres (editor), E. V. Glushkova, J. A. Johnson, H. Levato, B. Nordström, D. Pourbaix, G. Torres, S. Udry (contributors)
Subjects: Astrophysics (astro-ph)

Brief summaries are given on the following subjects: Radial velocities and exoplanets (Toward Earth-mass planets; Retired A stars and their planets; Current status and prospects); Toward higher radial velocity precision; Radial velocities and asteroseismology; Radial velocities in Galactic and extragalactic clusters; Radial velocities for field giants; Galactic structure -- Large surveys (The Geneva-Copenhagen Survey; Sloan Digital Sky Survey; RAVE); Working groups (WG on radial velocity standards; WG on stellar radial velocity bibliography; WG on the catalogue of orbital elements of spectroscopic binaries [SB9]).

On the Age of the Widest Very Low Mass Binary
Etienne Artigau, David Lafrenière, Loïc Albert, Rane Doyon
Comments: accepted for publication in The Astrophysical Journal
Subjects: Astrophysics (astro-ph)

We have recently identified the widest very low-mass binary (2M0126AB), consisting of an M6.5V and an M8V dwarf with a separation of ~5100 AU, which is twice as large as that of the second widest known system and an order of magnitude larger than those of all other previously known widest very low-mass binaries. If this binary belongs to the field population, its constituents would have masses of ~0.08 Msun, at the lower end of the stellar regime. However, in the discovery paper we pointed out that its proper motion and position in the sky are both consistent with being a member of the young (30 Myr) Tucana/Horologium association, raising the possibility that the binary is a pair of ~0.02 Msun brown dwarfs. We obtained optical spectroscopy at the Gemini South Observatory in order to constrain the age of the pair and clarify its nature. The absence of lithium absorption at 671 nm, modest
Introduction

• Provide background for experiment
• Historical significance
• Qualitative overview of work described in remainder of paper.
Method

• Diagrams, pictures
• List *major* equipment
• Description of experimental procedure
Data and Results

- Tables
- Graphs
- Results of calculations
- Don't forget: A paper is a *narrative*. Text needs to describe and tie the figures and results together
Data and Results

- Tables
- Graphs
- Results of calculations
- Don't forget: A paper is a narrative. Text needs to describe and tie the figures and results together.
# Tables

Table 8. Clusters of cosmic rays reported by AGASA. Equatorial coordinates have been taken from Hayashida et al (2000) and figure 23.

<table>
<thead>
<tr>
<th></th>
<th>RA</th>
<th>DEC</th>
<th>Date</th>
<th>UT</th>
<th>$\times 10^{19}$ eV</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>1$^h$15$^m$</td>
<td>21.1°</td>
<td>95/12/03</td>
<td>21:32:47</td>
<td>21.3</td>
</tr>
<tr>
<td></td>
<td>1$^h$14$^m$</td>
<td>20.9°</td>
<td>95/10/29</td>
<td>00:32:16</td>
<td>5.07</td>
</tr>
<tr>
<td>C2</td>
<td>11$^h$29$^m$</td>
<td>57.1°</td>
<td>92/08/01</td>
<td>13:00:47</td>
<td>5.50</td>
</tr>
<tr>
<td></td>
<td>11$^h$14$^m$</td>
<td>57.6°</td>
<td>95/01/26</td>
<td>03:27:16</td>
<td>7.76</td>
</tr>
<tr>
<td></td>
<td>11$^h$13$^m$</td>
<td>56.0°</td>
<td>98/04/04</td>
<td>20:07:03</td>
<td>5.35</td>
</tr>
<tr>
<td>C3</td>
<td>18$^h$59$^m$</td>
<td>47.8°</td>
<td>91/04/20</td>
<td>08:24:49</td>
<td>4.35</td>
</tr>
<tr>
<td></td>
<td>18$^h$45$^m$</td>
<td>48.3°</td>
<td>94/07/06</td>
<td>20:34:54</td>
<td>13.4</td>
</tr>
<tr>
<td>C4</td>
<td>4$^h$38$^m$</td>
<td>30.1°</td>
<td>86/01/05</td>
<td>19:31:03</td>
<td>5.47</td>
</tr>
<tr>
<td></td>
<td>4$^h$41$^m$</td>
<td>29.9°</td>
<td>95/11/15</td>
<td>04:27:45</td>
<td>4.89</td>
</tr>
<tr>
<td>C5&lt;sup&gt;a&lt;/sup&gt;</td>
<td>16$^h$06$^m$</td>
<td>23.0°</td>
<td>96/01/11</td>
<td>09:01:21</td>
<td>14.4</td>
</tr>
<tr>
<td></td>
<td>15$^h$58$^m$</td>
<td>23.7°</td>
<td>97/04/10</td>
<td>02:48:48</td>
<td>3.89</td>
</tr>
<tr>
<td>C6</td>
<td>14$^h$17$^m$</td>
<td>37.7°</td>
<td>96/12/24</td>
<td>07:36:36</td>
<td>4.97</td>
</tr>
<tr>
<td></td>
<td>14$^h$08$^m$</td>
<td>37.1°</td>
<td>00/05/26</td>
<td>18:38:16</td>
<td>4.89</td>
</tr>
<tr>
<td>C7&lt;sup&gt;b&lt;/sup&gt;</td>
<td>3$^h$45$^m$</td>
<td>44.9°</td>
<td>98/10/27</td>
<td>00:45:37</td>
<td>6.11</td>
</tr>
<tr>
<td></td>
<td>3$^h$41$^m$</td>
<td>46.6°</td>
<td>Unknown</td>
<td>Unknown</td>
<td>Unknown</td>
</tr>
</tbody>
</table>

<sup>a</sup> Cluster C5, consisting of one event with energy below the typical energy threshold of $4 \times 10^{19}$ eV, was generally omitted in later publications.

<sup>b</sup> The arrival time and energy of the second event comprising C7 has not been made public.
Figures

- Numbered
- Include caption (usu. bottom)
- Note that all symbols are described in caption.

**Figure 23.** AGASA events with energy above $4 \times 10^{19}$ eV superimposed on a skymap, in equatorial coordinates. Small circles represent events with energies of $(4-10) \times 10^{19}$ eV, small squares represent events with energies of $\geq 10^{20}$ eV. Clusters C1–C7 (C5 excluded) are identified, doublets with larger circles. The curves for the galactic (crossing galactic center, GC) and supergalactic planes are also shown. Figure taken from the AGASA web site (AGASA Collaboration 2003).
Graphs

- Symbols labeled
- Side-by-side saves space, also shows connections (optional!)

Figure 11. Left: flux measurements in the Second Knee energy range. The shown fits are our calculation. Right: flux measurements in the Second Knee energy range, scaled so that the flux agrees with the Fly’s Eye result at 10^{18} eV. The scaled data points were fit to a broken power law spectrum in a global fit, with the result shown.
Discussion

- Comparison with model.
- What are dominant sources of uncertainty?
- Suggest improvements to existing experiment, or new experiments.
Conclusion

• One paragraph summary of paper
• Should include recap of all major numerical results
• Recap of your main inferences
  – Model works or doesn't work
  – Experiment is/isn't a good way of testing the model.
References

• Use original references where possible
• Different journals have different preferred formats.
• For the “Physics 3719” Journal we'll use


• For books:
Other Guidelines

• Use same rules of grammar, etc that you would use in English class
  – Each sentence has a noun and a verb.
  – Each paragraph has a “theme” sentence, usually at the beginning or end

• Be consistent with verb tense; past or present?

• Avoid slang or jargon

• “Passive voice” vs “Active voice”...
Passive versus Active Voice

- “Active” voice or first person:
  I led the pigeons to the flag...

- “Passive” voice or impersonal:
  The pigeons were led to the flag...

- Many people feel strongly that passive voice is appropriate for scientific writing.

- JB's not so sure...
  - Can feel awkward, esp. in papers with few authors
  - Wishy-washy?

- Write as feels natural to you; but be consistent.