Intermediate Lab

PHYS 3870

Lecture 1

Introduction

Intermediate Lab

PHYS 3870

Class Administration
and
Syllabus

Intermediate Lab

PHYS 3870

Class:	MW	11:30 - 2:20	SER 109/132/138
Instructor:	J.R. Dennison		SER 222D
	797-2936	JR.Dennison@usu.edu	
Office Hours:	MW 2:30-3:30		
Assistant Instructor:	Jonathan Price jonathanprice1@live.com		SER 209

Class Web Site: http://www.physics.usu.edu/dennison/3870-3880/IntermediateLab.htm

Intermediate Lab Philosophy

PHYS 3870

It is important that students bring a certain ragamuffin barefoot irreverence to their studies; they are not here to worship what is known, but to question it.

–Jacob Bronowski, The Ascent of Man 1973

If you're not prepared to be wrong, you'll never come up with anything original.

–Sir Ken Robertson, TED Talk 2006

Take chances, make mistakes, get messy.

–Miss Frizzle, The Magic School Bus 1994

Intermediate Lab

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Summary of Introductory Physics Laboratory Goals*

I. **The Art of Experimentation:** The introductory laboratory should engage each student in
ıt experiences with experimental processes, including some experience designing investigations.
II **Experimental and Analytical Skills:** The laboratory should help the student develop a
ʼay of basic skills and tools of experimental physics and data analysis.
II **Conceptual Learning:** The laboratory should help students master basic physics concepts.
IV **Understanding the Basis of Knowledge in Physics:** The laboratory should help students to
ıd the role of direct observation in physics and to distinguish between inferences based on
ıd on the outcomes of experiments.
V. **Developing Collaborative Learning Skills:** The laboratory should help students develop
ıtive learning skills that are vital to success in many lifelong endeavors.

Many of the goals are not explicit in traditional laboratory programs. However. the American Association of Physics Teachers believes that laboratory programs should be designed with these five fundamental goals in mind.

I add: **Communicating** results and ideas.

* American Association of Physics Teachers, "Goals of the Introductory Physics Laboratory, American Journal of Physics, **66**(6), 483-485 (1998).

Intermediate Lab

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How the Intermediate Lab fits into the "Physics Skills Classes" at USU

Goals of AAPT*	Physics Courses				
	Gen. Physics Labs	Scientific Computing	Intermediate Lab	Advanced Lab	Waves
Art of Experimentation			x	X	
Experimental & Analytic Skills		X	X	x	X
Conceptual Learning	X		x	X	X
Basis of Knowledge in Physics	X		X	x	
Collaborative Learning Skills	x		X	x	
Communications Skills	x	X	X	X	

X Main Emphasis **x** Minor Emphasis

* American Association of Physics Teachers, "Goals of the Introductory Physics Laboratory, American Journal of Physics, **66**(6), 483-485 (1998).

Intermediate Lab

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In terms of the above discussion, the Intermediate Lab is intended to:

a)Teach you how to model systems
- **(1) Start with simple systems and simple models**
- **(2) Emphasize the modeling process, rather than specific systems or models**

b) Teach you how to evaluate the effectiveness of models

c) Develop experimental and analytic skills

d) Emphasize communication of results and formulation of conclusions

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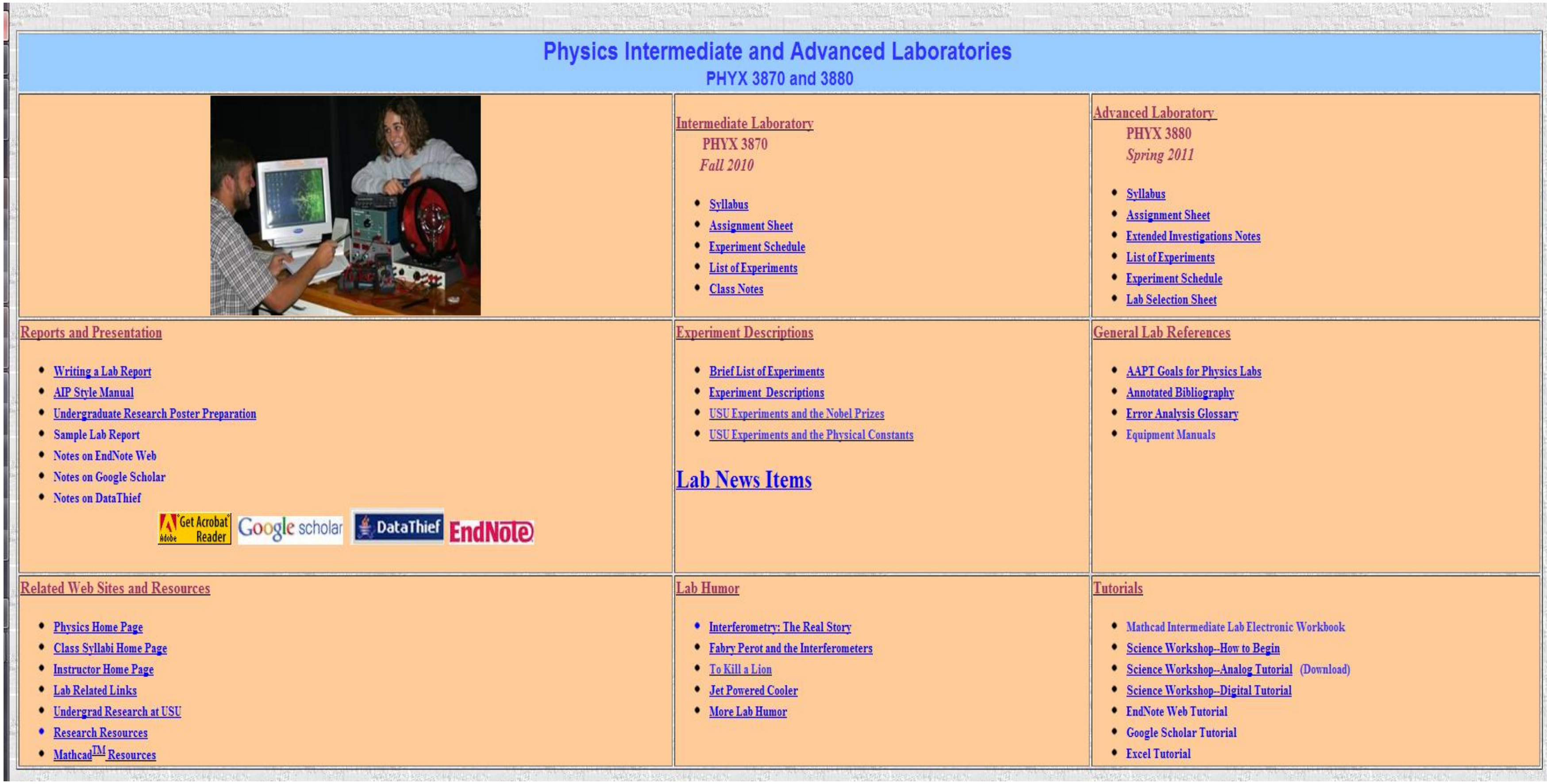

Physics Intermediate and Advanced Laboratories

PHYX 3870 and 3880

Intermediate Laboratory

PHYX 3870

Fall 2010

- Syllabus
- Assignment Sheet
- Experiment Schedule
- List of Experiments
- Class Notes

Advanced Laboratory

PHYX 3880

Spring 2011

- Syllabus
- Assignment Sheet
- Extended Investigations Notes
- List of Experiments
- Experiment Schedule
- Lab Selection Sheet

Reports and Presentation

- Writing a Lab Report
- AIP Style Manual
- Undergraduate Research Poster Preparation
- Sample Lab Report
- Notes on EndNote Web
- Notes on Google Scholar
- Notes on DataThief

Get Acrobat Reader | Google scholar | DataThief | EndNote

Experiment Descriptions

- Brief List of Experiments
- Experiment Descriptions
- USU Experiments and the Nobel Prizes
- USU Experiments and the Physical Constants

Lab News Items

General Lab References

- AAPT Goals for Physics Labs
- Annotated Bibliography
- Error Analysis Glossary
- Equipment Manuals

Related Web Sites and Resources

- Physics Home Page
- Class Syllabi Home Page
- Instructor Home Page
- Lab Related Links
- Undergrad Research at USU
- Research Resources
- Mathcad[TM] Resources

Lab Humor

- Interferometry: The Real Story
- Fabry Perot and the Interferometers
- To Kill a Lion
- Jet Powered Cooler
- More Lab Humor

Tutorials

- Mathcad Intermediate Lab Electronic Workbook
- Science Workshop--How to Begin
- Science Workshop--Analog Tutorial (Download)
- Science Workshop--Digital Tutorial
- EndNote Web Tutorial
- Google Scholar Tutorial
- Excel Tutorial

Class Web Site: http://www.physics.usu.edu/

Go to Classes/Class Websites

Intermediate Lab

PHYS 3870

Prerequisites:

- *General Physics (PHYS 2210 and 2220),*
- *Introduction to Modern Physics (PHYS 2710)*
- *Introduction to Computer Methods in Physics (PHYS 2500).*

Students will not be admitted without the prerequisites without explicit permission from the instructor.

INTERMEDIATE LABORATORY I - PHYS 3870
SYLLABUS
Fall 2015

It is important that students bring a certain ragamuffin barefoot irreverence to their studies; they are not here to worship what is known, but to question it. –*Jacob Bronowski, The Ascent of Man*

Class: 11:30 - 2:20 MW SER 109/132/138 http://physics.usu.edu
Instructor: JR Dennison, Physics Department SER 222D (435) 797-2936 JR.Dennison@usu.edu
Office Hours: *During lab time, MW 11:30-2:30, or by appointment*
Assistants: Jonathan Price SER 209 jonathanprice1@live.com
Class Web Site: http://www.physics.usu.edu/dennison/3870-3880/IntermediateLab.htm

Prerequisites: *General Physics* (PHYS 2210 and 2220), *Introduction to Modern Physics* (PHYS 2710) *Introduction to Computer Methods in Physics* (PHYS 2500).
Students will not be admitted without the prerequisites without explicit permission from the instructor.

Objectives: This course is intended to address all five goals for physics laboratory courses identified in the AAPT *Goals of the Introductory Physics Laboratory* handout. During this semester, particular emphasis is placed on: (1) experimental and analytic skills including experimental techniques, computer interfacing, data analysis, and error analysis; and (2) developing collaborative learning skills through work with a lab partner. In addition, written and oral communication skills are stressed.

Texts: J. R.Taylor, An Introduction to Error Analysis, 2nd ed. (Univ. Science Books, Mill Valley, CA, 1997). **REQUIRED**
D.C. Baird, Experimentation: An Introduction to Measurement Theory and Experiment Design, 3rd ed. (Prentice-Hall, Englewood Cliff, NJ, 1995). **RECOMMENDED**
AIP Style Manual, 4th ed. (Am. Institute of Physics, New York, 1990). **Available via web site**
MathCAD Version 14, (Mathsoft, Cambridge, MA, 2007). **RECOMMENDED COMPUTER ANALYSIS PROGRAM** Available for purchase or in SER 109, 132, 138.
Additional references are listed in the attached *Annotated Bibliography*.

Notebook: A bound Lab Notebook is required. All data, notes, calculations and scratch work should be kept in the notebook.
NO EXPERIMENT WILL BE ACCEPTED UNLESS IT IS RECORDED IN A NOTEBOOK

Grading: Problem Sets (25%): Turn in all even numbered problems on error analysis listed on the attached *Assignment Sheet*. You are encouraged to use *Mathcad* to solve these problems. *Mathcad* solutions to the odd numbered problems will be posted. A penalty will be imposed for late assignments.
Experiment Reports (75%): Reports for each of three experiments will count 25% of the total grade. Reports must be turned in before beginning the next experiment. You may revise either of the first two reports, based on instructor comments, and receive the average grade of the two marks for the final grade for the experiment. *There will be a half letter grade penalty for each class period the report is late. Grades may also be reduced if the lab and equipment is not left clean and orderly.* A *Lab Report Grade Form* is available.

Assignments: There will be a series of eight lectures during the first six weeks of the semester. Reading assignments and problems are listed on the attached *Assignment Sheet*. Lab partners and experiment selection will be determined during the second week of classes. A *Schedule of Experiments* will be posted during the third week of classes. Partners will schedule meetings with the instructor outside class to preview experimental proceedures.

Complete three experiments on the topics of your choice from the attached *List of Experiments*. The experiments are designed to take about eight hours each for data collection. Experiments should be performed in pairs. One experiment will require a brief report (four page limit). One experiment will require full report (no page limit). The final report format is an oral presentation prepared jointly by lab partners. Refer to the handouts *Content of Lab Reports* and *Descriptions of Experiments* and *Poster Preparation* for further details.

Disability Resource Center: Students with ADA-Documented physical, sensory, emotional or medical impairments may be eligible for reasonable accommodations. Veterans may also be eligible for services. All accommodations are coordinated through the Disability Resource Center (DRC) in Room 101 of the University Inn. (435)797-2444 voice, (435)797-0740 TTY, (435)797-2444 VP, or toll free at 1-800-259-2966. Please contact the DRC as early in the semester as possible. Alternate format materials (Braille, large print or digital) are available with advance notice.

Honor Code: The honor code will be strictly enforced in this course. Any suspected violations of the honor code will be promptly reported to the honor system. For more information please visit: http://www.usu.edu/policies/PDF/Acad-Integrity.pdf

Class Fee: A $40 fee per semester is charged for this class to help cover the expenses for expendable supplies and computer usage. Please be aware that the equipment used in this lab was acquired over many years, at a cost well in excess of $250,000; please treat it with appropriate care and respect.

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Texts:

J. R.Taylor, An Introduction to Error Analysis, 2nd ed. (Univ. Science Books, Mill Valley, CA, 1997). **REQUIRED**

D.C. Baird, Experimentation: An Introduction to Measurement Theory and Experiment Design, 3rd ed. (Prentice-Hall, Englewood Cliff, NJ, 1995). **RECOMMENDED**

AIP Style Manual, 4th ed. (Am. Institute of Physics, New York, 1990). **Available via web site**

MathCAD Version 13, 14 or 15, (Mathsoft, Cambridge, MA, 2007). **RECOMMENDED COMPUTER ANALYSIS PROGRAM** Available for purchase or in SER 109 and SER 231 (see Physics Office in SER 250 for key).

New for this year: Mathcad and other programs are available on Citrix

Additional references are listed in the attached *Annotated Bibiliography*.

Intermediate Lab

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Equipment In The Intermediate Lab:

- **A $40 fee per semester is charged for this class to help cover the expenses for expendable supplies and computer usage.**

- **Please be aware that the equipment used in this lab was acquired over many years, at a cost well in excess of $250,000; please treat it with appropriate care and respect.**

- **I expect use and wear on the equipment. We cannot afford abuse or misuse of the equipment. IF YOU DO NOT KNOW HOW TO DO SOMETHING ASK FIRST!!!**

- **PLEASE CLEAN UP AFTER YOURSELF.**

Intermediate Lab

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Experiments and Reports:

Experiment Reports (75%): Reports for each of three experiments will count 25% of the total grade. Reports must be turned in before beginning the next experiment. You may revise either of the first two reports, based on instructor comments, and receive the average grade of the two marks for the final grade for the experiment. *There will be a half letter grade penalty for each class period the report is late. Grades may also be reduced if the lab and equipment is not left clean and orderly.* A *Lab Report Grade Form* is available.

Assignments: Complete three experiments on the topics of your choice from the attached *List of Experiments*. The experiments are designed to take about six to eight hours each for data collection. Experiments should be performed in pairs. One experiment will require a **brief report** (4 page limit). One experiment will require **full report** (no page limit). The final report format is **an oral presentation** prepared jointly with your lab partner. Refer to the handouts *Content of Lab Reports* and *Descriptions of Experiments* for further details.

Intermediate Lab

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Week	Lecture	Reading	Problems in Taylor	Assignments Deadlines
1 **(8/31/15 to 9/4/15)**	Introduction Experiment Design	Baird, Ch. 5 AIP Style Manual: pp. 1-30 Taylor: Preface	HW#1: Baird: 5.7,5.15, 5.18, 5.23 (problems posted on web)	
	Error Analysis Uncertainty Error Propagation	Taylor: Ch. 1 & 2 Taylor: Ch. 3	HW#1: 2.2, 2.3, 2.8, 2.9, 2.17, 2.19, 2.24, 2.26,2.28	
2 **(9/7/15 to 9/11/15)**	**(Memorial Day**	**No Class on Mon. 9/7)**		Problem Set 1 due 9/9/15
	Statistical Analysis Distributions Rejection of Data	Taylor: Chs. 4, 5 & 6	HW#2: 3.3, 3.4, 3.7, 3.11, 3.18, 3.40, 3.46	Experiments selected 9/9/15 Preview meetings
3 **(9/14/15 to 9/18/15)**	Linear Regression	Taylor: Chs. 7 & 8	HW#2: 4.5, 4.9, 4.13, 4.17, 4.23, 4.28, 5.4, 5.12, 5.15, 5.35, 6.2	Preview meetings
	Experiment 1 9/16/15 to 10/14/15			Problem Set 2 due 9/16/15 Preview meetings
4 **(9/21/15 to 9/25/15)**	Nonlinear Regression Chi Squared Tests	Taylor: Ch. 9 & 12	HW#3: 8.2, 8.7, 8.20, 8.24, 8.25, 9.9, 9.15	Preview meetings
	Experiment 1 9/16/15 to 10/14/15			
5 **(9/28 to 10/2/15)**	Lecture: Report Writing and Lab Software	Taylor: Ch. 12	HW#4: 12.2, 12.7, Data Analysis Exercise, Lit. Search Exercise	Problem Set 3 due 9/28
	Experiment 1 9/16/15 to 10/14/15			
6 (10/5/ to10/9/15)	**Experiment 1** 9/16/15 to 10/14/15			Problem Set 4 Due 10/5
7 (10/12 to 10/16/15)	**Experiment 1** 9/16/15 to 10/14/15	**4Corners Meeting 10/16-17/15**		Exp. 1 Due 10/19/15

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Week	Lecture	Reading	Problems in Taylor	Assignments Deadlines
5 **(9/28 to 10/2/15)**	Lecture: Report Writing and Lab Software	Taylor: Ch. 12	HW#4: 12.2, 12.7, Data Analysis Exercise, Lit. Search Exercise	Problem Set 3 due 9/28
	Experiment 1 9/16/15 to 10/14/15			
6 (10/5/ to10/9/15)	**Experiment 1** 9/16/15 to 10/14/15			Problem Set 4 Due 10/5
7 (10/12 to 10/16/15)	**Experiment 1** 9/16/15 to 10/14/15	**4Corners Meeting 10/16-17/15**		Exp. 1 Due 10/19/15
8 (10/19 to 10/23/15)	**Experiment 2**	10/19/15 to 11/9/15		
9 (10/26 to 10/30/15)	**Experiment 2**	10/19/15 to 11/9/15		
10 (11/2 to 11/6/15)	**Experiment 2**	10/19/15 to 11/9/15		
11 (11/9 to 11/13/15)	**Experiment 2**	10/19/15 to 11/9/15		Exp. 2 Due 11/11/15
	Experiment 3	11/11/15 to 12/7/15		Final day for 1st lab revisions 11/18/15
12 (11/16 to 11/20/15)	**Experiment 3**	11/11/15 to 12/7/15		**All Work Due 12/11/15**
13 (11/23 to 11/27)	**(Thanksgiving Break**	**No class 11/25/15 to 11/29/15)**		**NO EXCEPTIONS!!!**
14 (11/30 to 12/4)	**Experiment 3**	11/11/15 to 12/7/15		
15 (12/7 to 12/11)	**Experiment 3**	11/11/15 to 12/7/15		**THIS MEANS YOU!!!**
	Final Oral Presentation			12/9/15

Intermediate and Advanced Lab

PHYS 3870-3880

Intermediate Lab PHYS 3870			
Error Analysis & Experimental Design	**Experiment 1** 3 weeks Short Report	**Experiment 2** 3 Weeks Long Report	**Experiment 3** 3 weeks Oral Presentation

Advanced Lab PHYS 3880		
Experiment 4 3 weeks Short Report	**Experiment 5** **Extended Investigation** 7 weeks Long Report	**Experiment 6** 3 weeks Poster Presentation

Intermediate Lab

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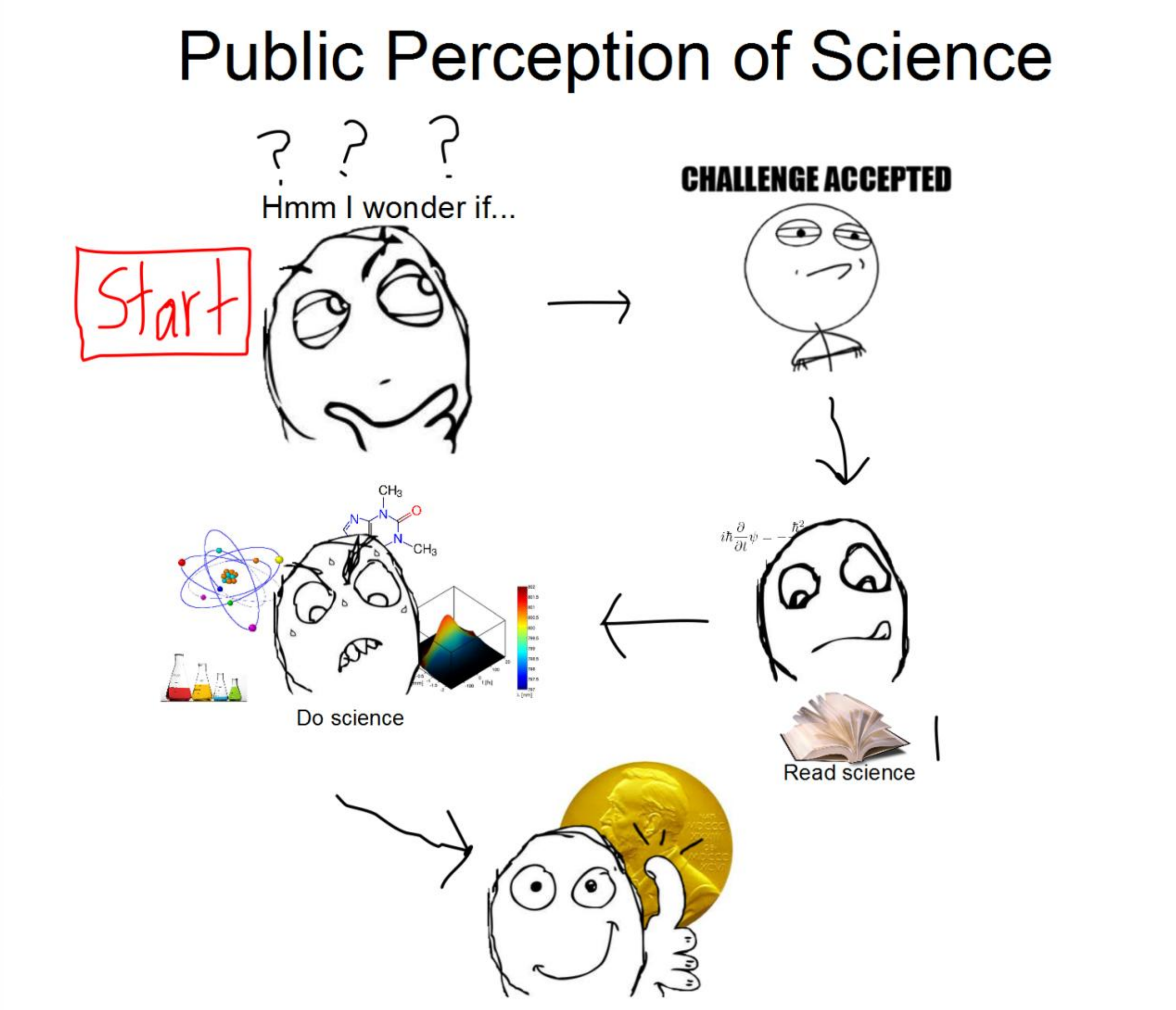
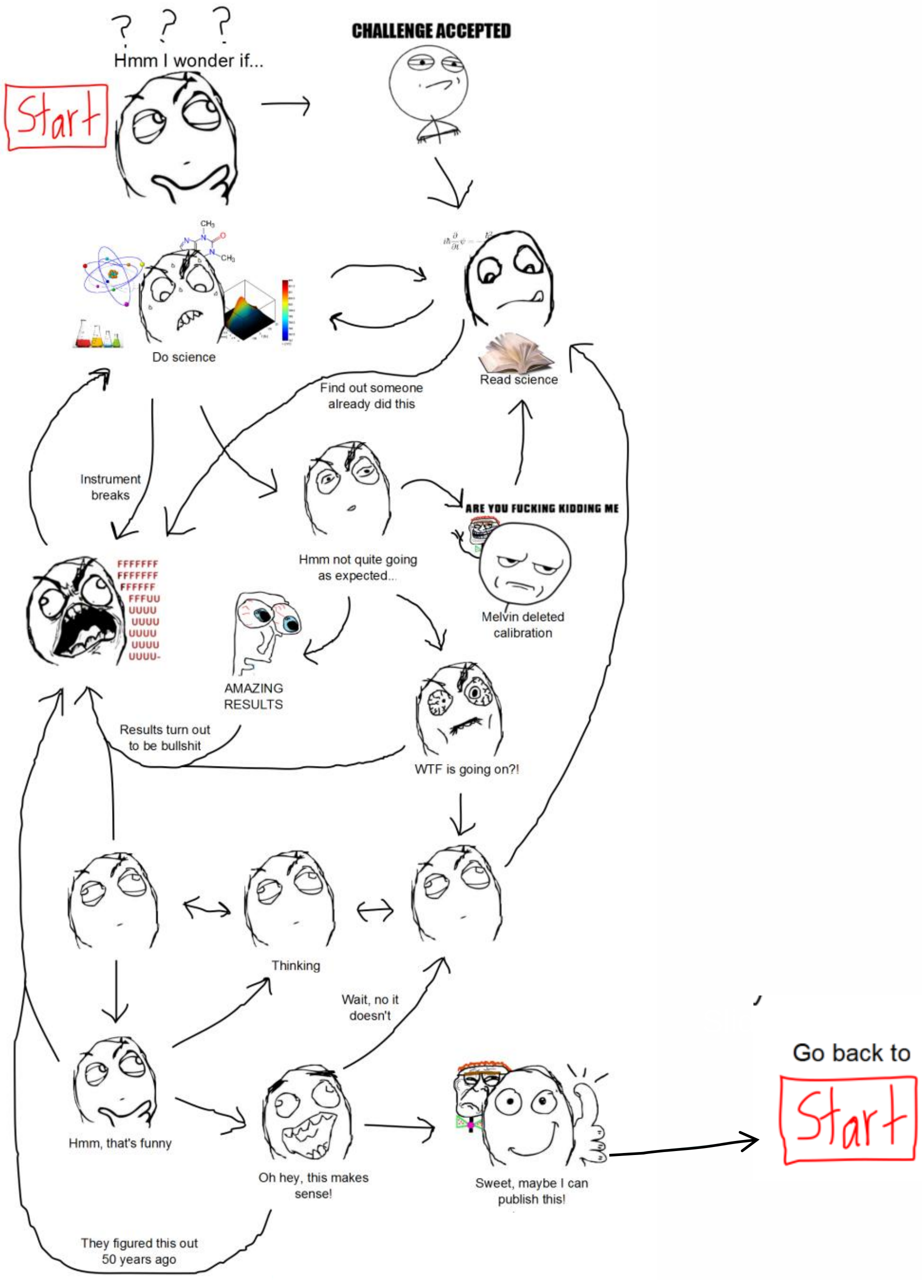
We're going to "do physics" in this lab!

So this begs the question:

What is Experimental Physics?

What is “Doing Physics”?





What is Really "Doing Physics"?

What is Physics?

“Study of the basic nature of matter and the interactions that govern its behavior.”

BORING!!!

“How Stuff Works.”

True, but vague.

“Common Sense Approach to How Things Work” (with units!)

Common Sense—A minimal set of simple, straightforward guides.

Units—Predictions on a quantitative level

What are the major subfields in Physics?

Classical Physics *(pre-20th century)*

- Mechanics → forces, motion
- Thermodynamics → heat, temperature
- Electricity and magnetism → charge, currents
- Optics → light, lenses, telescopes

Modern Physics *(20th and 21st centuries)*

- Atomic and nuclear → radioactivity, atomic power
- Quantum mechanics
- Particle physics

} → basic structure of matter

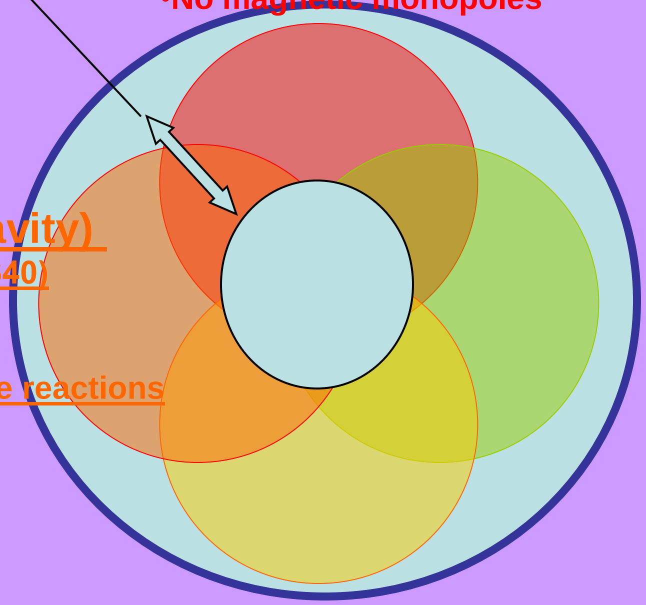
- Condensed matter → solids & liquids, computers, lasers
- Complex systems→ chaos, complexity, fractals, critical exponents
- Relativity, Cosmology → universe, life!

State of Physics *cira* 1895

Statistical Mechanics
- 3 Laws of Thermodynamics
- Kinetic Theory

Electricity & Magnetism
Maxwell Equations (c 1880)
- Gauss' Law
- Faraday's Law
- Ampere's Law
- No magnetic monopoles

Conservation Laws
- Energy
- Linear & Angular Momentum



Mechanics (Gravity)
Newton's Laws (c 1640)
1-Law of inertia
2-F=ma
3-Equal and opposite reactions

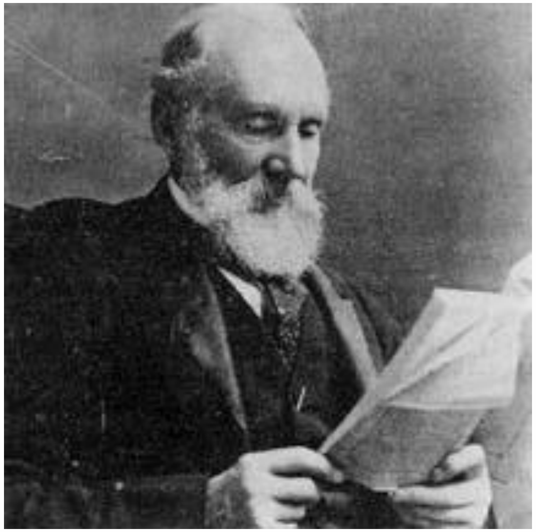
Limits of pre-Modern Physics

Dimension	Range of Applicability	Range of Application
Length	10^{-6} to 10^{+8} m	Smoke particle (Brownian Motion) to the solar system
Mass	10^{-9} to 10^{+31} kg	Dust particles to solar mass
Time	10^{+10} to 10^{+17} sec^{-1} 10^{-3} to 10^{+9} sec	Microwave to UV light Smallest timing increments (msec) to celestial motions (centuries)
Velocity	10^{-6} to 10^{+5} m/s	Small particles to celestial motion

State of Physics *cira* 1895

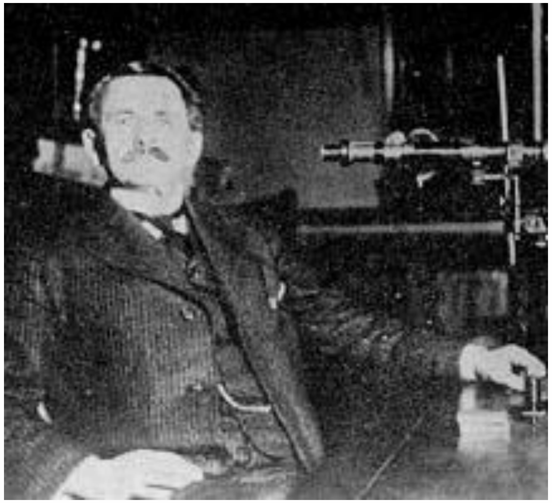
Lord Kelvin—arguably the greatest physicist of his day:

- Strong opponent of existence of atoms
- "There is nothing new to be discovered in physics now. All that remains is more and more precise measurement." (British Assoc., 1900)



Albert A Michleson—the first US Physics Nobel laureate:

- "The grand underlying principles have been firmly established...further truths of physics are to be looked for in the sixth place of decimals" *(Science*, 1892)

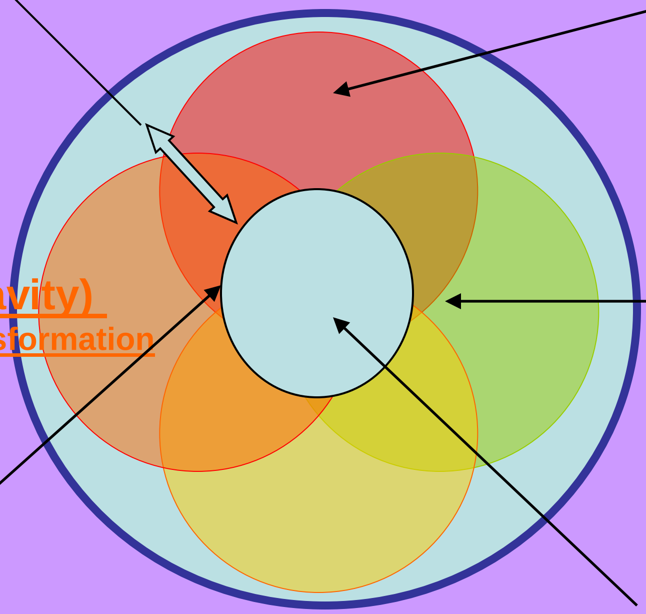


Inconsistencies in Physics *cira* 1900

Statistical Mechanics
- Boltzmann Distribution
- Entropy and counting states

Electricity & Magnetism
- Medium for propagation of light
- Obeys Lorentz transformation

- Blackbody radiation
- Wein's Law
- Photoelectric effect
- Diffraction of x rays



Mechanics (Gravity)
Obeys Galilean transformation

- Discrete atomic spectra
- Radioactive decay

- Brownian motion

- **Existence of Atoms!**

Then All Hell Broke Lose

“Thirty Years That Shook Physics”

- 1887 *Michelson*-Morley exp. debunks “ether”
- 1895 Rontgen discovers x rays
- 1897 Becquerel discovers radioactivity
- 1897 Thomson discovers the electron
- 1900 Planck proposes energy quantization
- 1905 Einstein proposes special relativity
- 1915 Einstein proposes general relativity
- 1911 Rutherford discovers the nucleus
- 1911 Braggs and von Laue use x rays to determine crystal structures
- 1911 Ones finds superconductors
- 1913 Bohr uses QM to explain hydrogen spectrum
- 1923 Compton demonstrates particle nature of light
- 1923 de Broglie proposes matter waves
- 1925 Davisson & Germer prove matter is wavelike
- 1925 Heisenberg states uncertainty principle
- 1926 Schrodinger develops wave equation
- 1924-6 Boson and Fermion distributions developed

- **1949 Murphy's Law stated**


FIG. 151.—Hand of Professor Rt. Hon. Lord Kelvin.

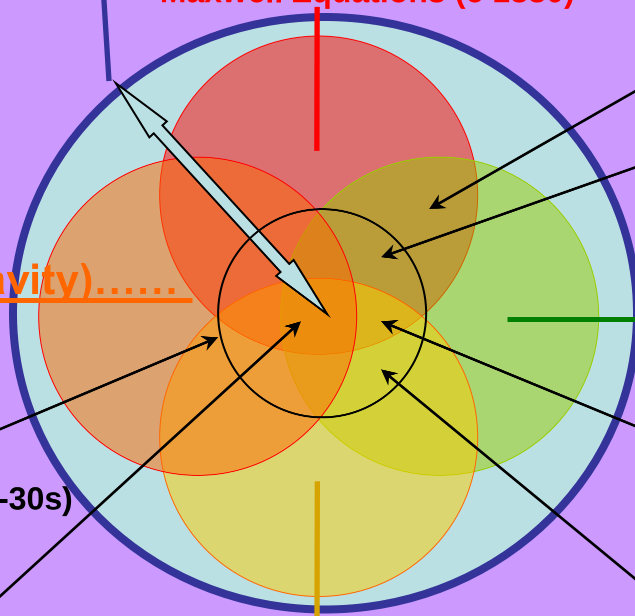
Silvanus P. Thompson, *Light: Visible and Invisible*, (MacMillan, New York, 1897).

Current State of Physics *cira* 2014

Statistical Mechanics (1860-1900s)
- Physics of many particles
- Fermions and Bosons
- Partitioning of Energy
- Thermodynamics
- Time and Entropy

Conservation Laws
- Energy
- Linear & Angular Momentum
- Charge, Spin, Parity
- Lepton and Baryon Number

Electricity & Magnetism
Maxwell Equations (c 1880)



Weinburg-Salom Model
- Unites E&M, Weak NF
- QED (1960s)

Mechanics (Gravity)……
General Relativity
Space and time

Weak Nuclear Force
Radioactivity

Quantum Mechanics
- Schrodinger/Dirac Equation (1920-30s)
- Probabilistic approach

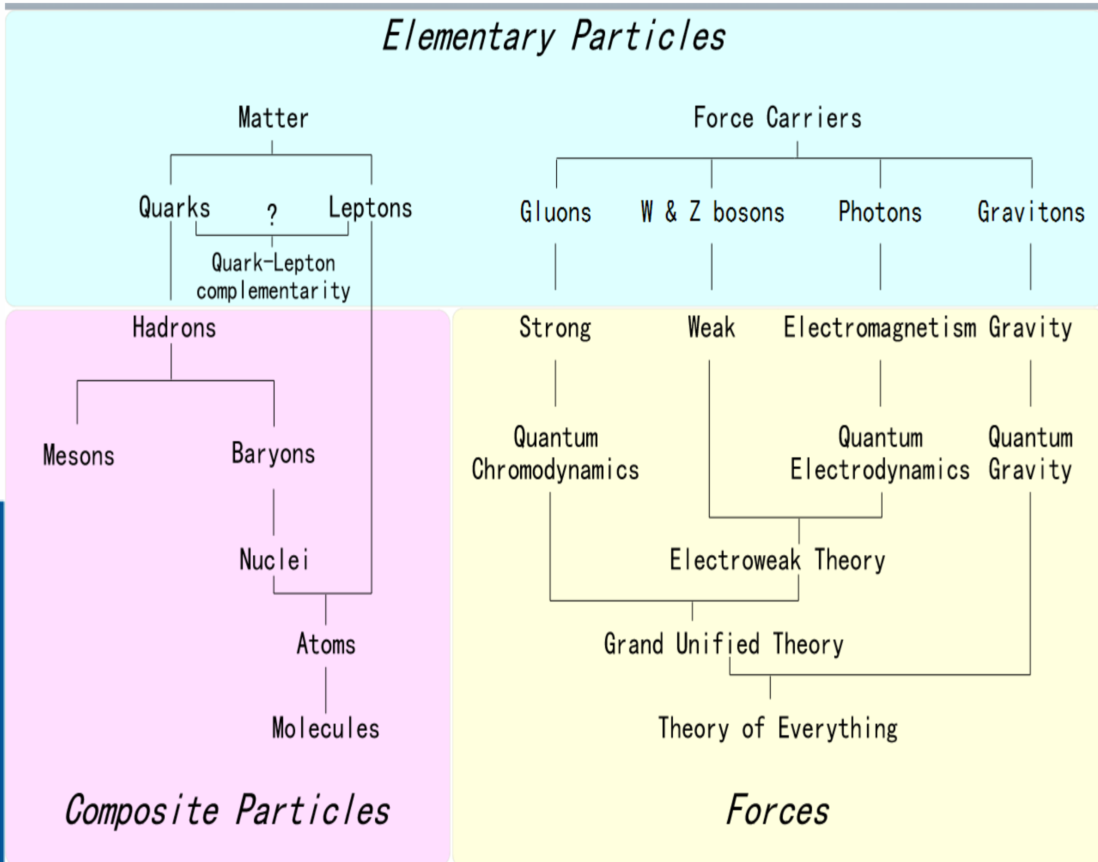
Grand Unified Theories
- Unifies E&M, Weak NF, Strong NF
- String Theories

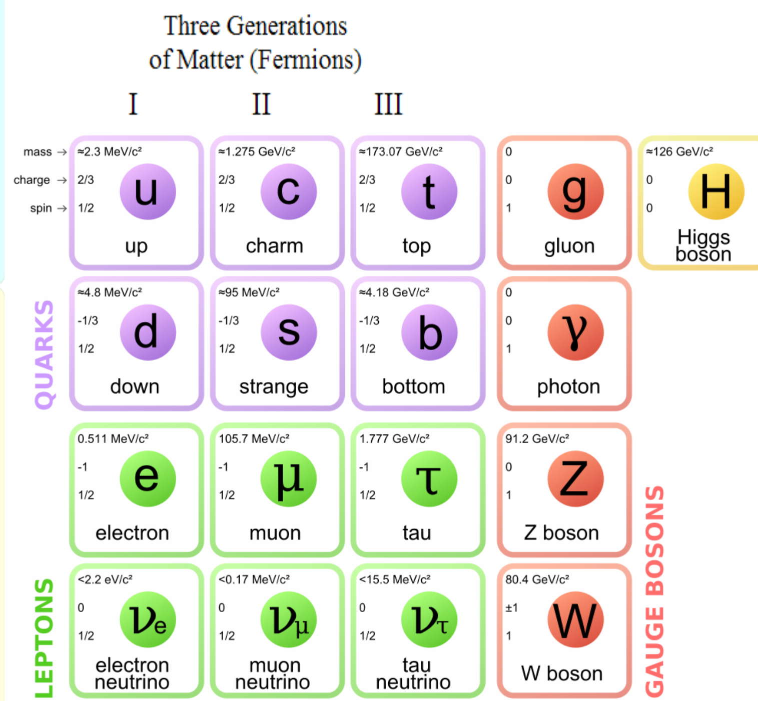
Theories of Everything
- Unifies E&M, Weak NF, Strong NF and Gravity

QCD (1970s)

Strong Nuclear Force
Composition of subatomic particles

Current State of Physics *cira* 2014





Limits of Current Modern Physics

Dimension	Range of Applicability	Range of Application
Length	10^{-18} to 10^{+26} m	Quark size to the universe size
Mass	10^{-31} to 10^{+40} kg	Electrons to galactic clusters
Time	10^{+3} to 10^{+22} sec^{-1} 10^{-16} to 10^{+17} sec	Radio to Gamma rays Sub-femtosecond spectroscopy to age of universe
Velocity	10^{-8} to 10^{+8} m/s	Sub-atomic particles to speed of light

Inconsistencies in Physics *cira* 2009

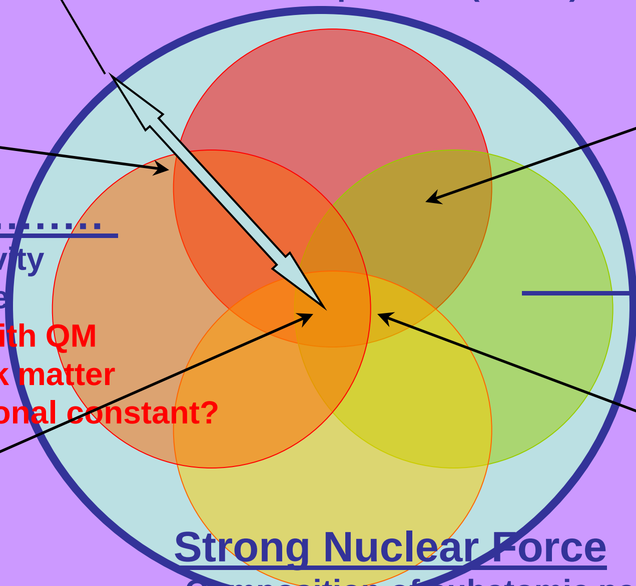
Statistical Mechanics
- Fermions, Bosons and Anyons
- Bose-Einstein Condensates
- Superconductivity
- Stellar Evolution
- SM of Black Holes
- Time and Entropy

Chaotic and complex systems

Conservation Laws
- Energy
- Linear & Angular Momentum
- Charge, Spin
- Lepton and Baryon Number

Electricity & Magnetism
Maxwell Equations (c1880)

Heavy Fermions and HTSC



Gravity………………
- General Relativity
- Space and time
- Inconsistent with QM
- Search for dark matter
- Fixed gravitational constant?

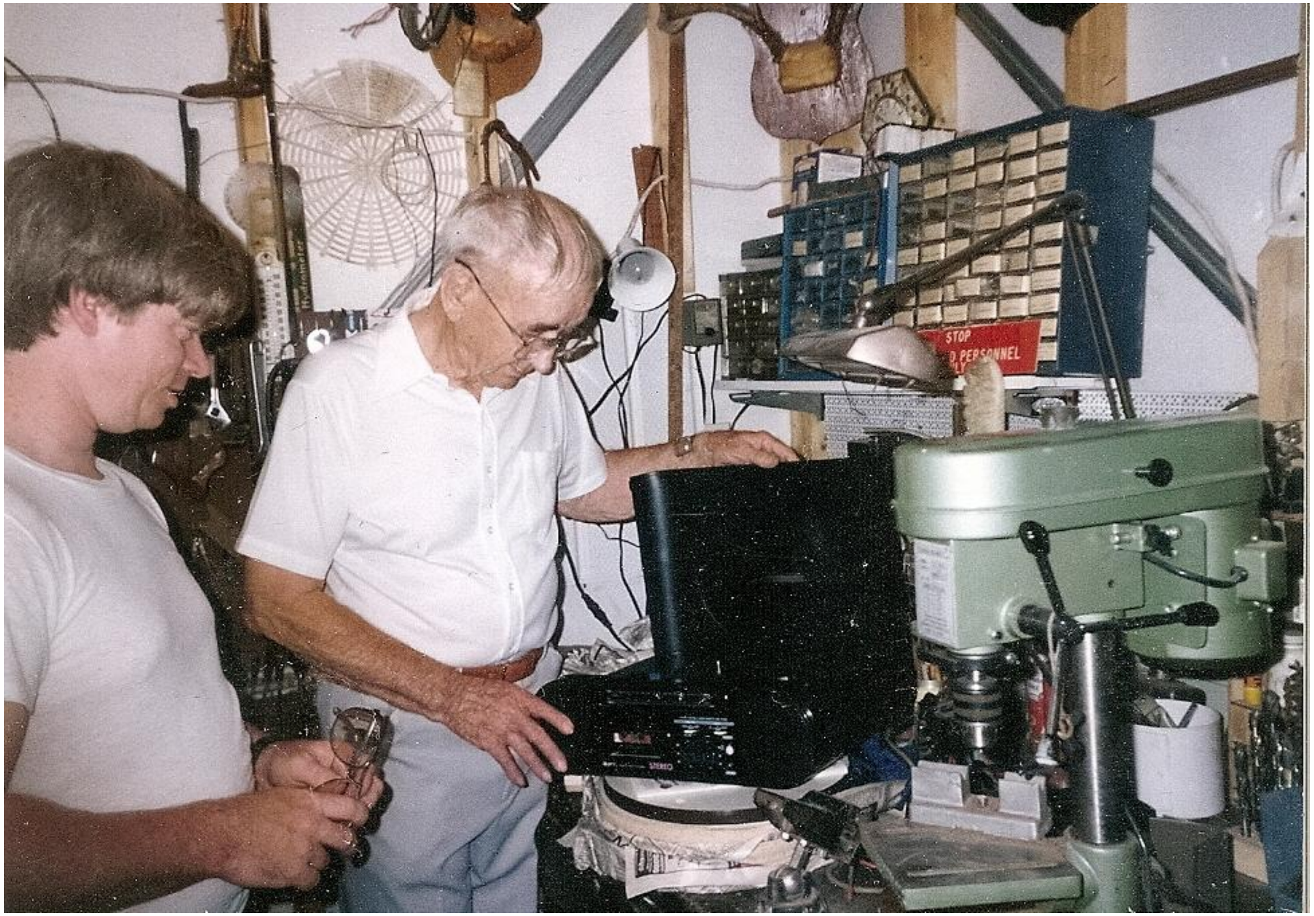
Weak Nuclear Force
- Radioactivity
- CPT violations?

GUT's and TOE's
- Combining Standard model and Gravity
- String Theory

Quantum Mechanics
- Existence of atoms
- Schrodinger/Dirac Equation
- Sub-atomic particles
- Probabilistic approach
- Teleportation
- Entwined states
- Sub-Planck length physics

Strong Nuclear Force
- Composition of subatomic particles
- Matter/anitmatter imbalance
- Decay ratios and particle masses
- ~~Search for Higgs Bosons~~
- Nature of strong hadron force
- Proton decay

I learned my best physics in a shed.



Speaking of shed…see http://www.physics.usu.edu/dennison/3870-3880/Humor/jet%20powered%20beer%20cooler__.pdf

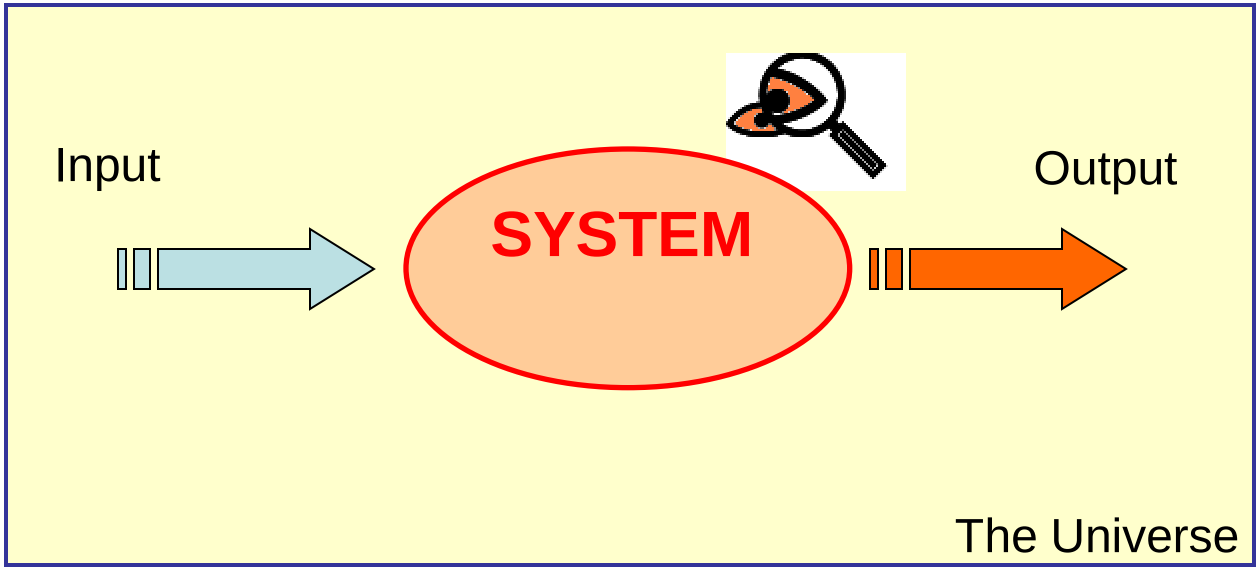
What is Experimentation?

Baird defines experimentation as the process of:

- **Identifying a portion of the world to study (the system)**
- **Obtaining information from this system**
- **Interpreting this result**

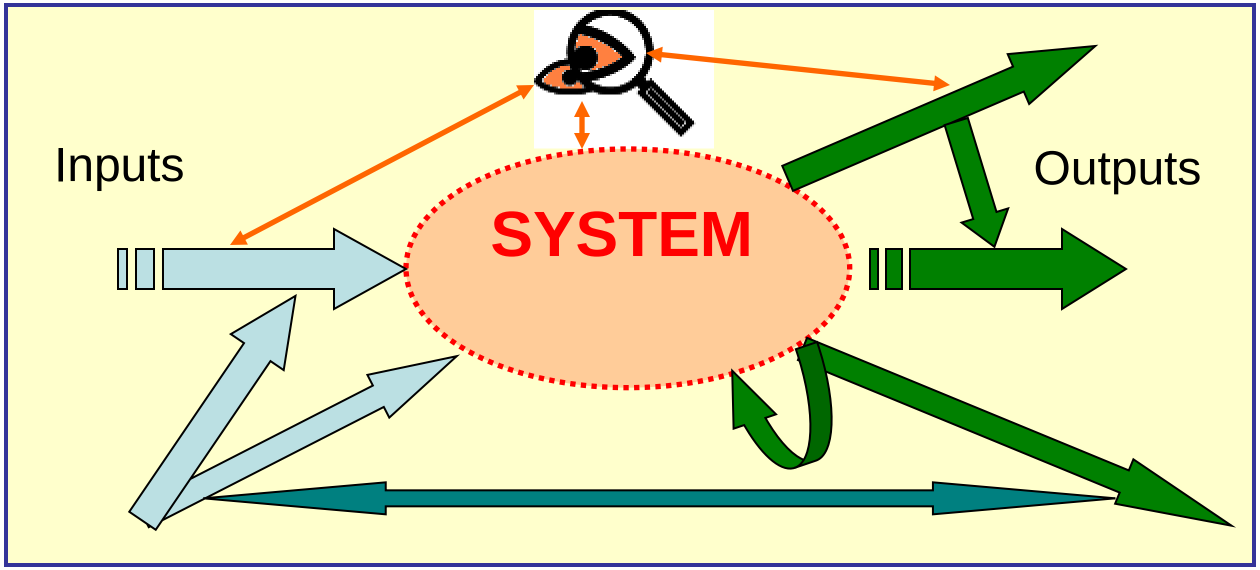
Observations of the Physical World

The Simplest (Ideal) System



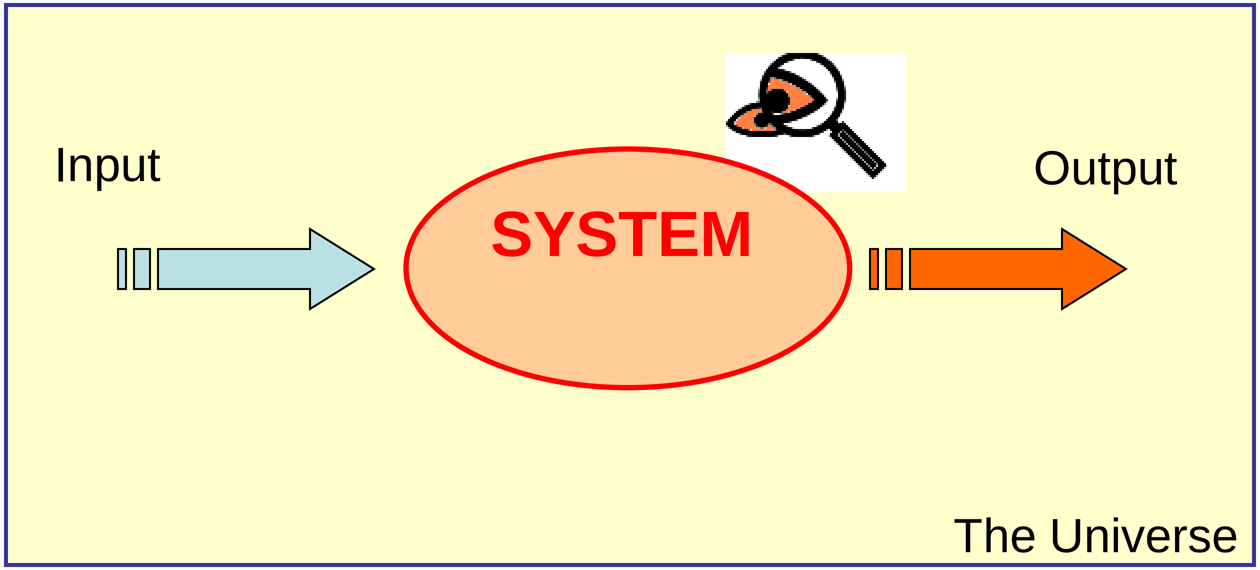
- **The system (portion of the world being studied) is well defined**
- **Single input (things we can control) affects system**
- **Single output (things we cannot control directly) results from interaction of system with input(s)**
- **Observations characterize the system to within the uncertainty of the measurements**

A Complex System



- **Complex (or ill defined) system and system boundaries**
- **Multiple inputs**
- **Multiple outputs**
- **Possible complicating interactions:**
  - **Between inputs**
  - **Between outputs**
  - **Between inputs and outputs**
  - **Between outputs and inputs**
  - **Between outputs and system**
  - **Between inputs and system**
  - **Between observations and system, inputs and outputs**

Uncertainties in Observations



- **Observations characterize the system to within the uncertainty of the measurements**
- **Uncertainties can arise from:**
  - **Limitations of instrumentation or measurement methods**
  - **Statistical fluctuations of the system**
  - **Inherent uncertainties of the system**
    - **- Quantum fluctuations**
    - **- Non-deterministic processes (e.g., chaos):**
      - **- There are systems where uncertainties dominate and preclude models predicting the outcome**
      - **- We will not (intentionally) deal with this type of system this semester.**

What is Science?

The scientific method goes further in:

- Developing a description (model) of the system behavior based on observation
- Generalizing this description (model) to other behavior and other systems
- That is to say, the scientific method is experimentation and modeling intertwined
- It is the ***scientific method*** that distinguishes science from other forms of endeavor

As Neils Bohr famously said,

"All science is either physics or stamp collecting."

Objectives of Science?

Science is:

- Science is the **process of modeling** the a portion of the physical world and using those models to predict the behavior of a larger portion of the physical world.
- Science is by nature an **experimental endeavor** (based on observation).
- **Interpretation of observations** to produce models (theories).
- **Interpretation of models** (theories) to predict system behavior.
- Good science is **generalized** to other (and often more complex) systems.
- Good science prefers the simplest model (This is referred to as the **Principle of Occam's Razor**).

Einstein Principle: A scientific theory should be as simple as possible, but no simpler. – Albert Einstein

What is a Model?

Models of the physical world

1. A **model**:
    a) Describes the system
    b) Proposes how input variables interact with the system to modify output variables
2. Models versus systems
    a) A system is real. Information about the system can be known incontrovertibly.
    b) Models are not real.
        (1) Models are mankind's descriptions of reality
        (2) Models can never be fact (period), though they can be very good descriptions of how real systems behave.
        (3) Neither Newton's Law's, nor Special Realitivity, nor Einstein's Equations for General Relativity, nor TOE (Theory of Everything) are the final answer; Nature is!

What is a Model?

Einstein Principle: A scientific theory should be as simple as possible, but no simpler. – Albert Einstein

3. **Modeling simple systems versus modeling complex systems**

   a) Modeling simple systems is easier, but often insufficient

   b) This brings up the point in the ***art of experimentation***; it is prudent to use the simplest model possible to get the desired level of predictions from your model.

   - **When are Newton's Laws, or Special Relativity, or General Relativity sufficient?**
   - **Should we worry about the Quantum nature of a system or is a classical approach sufficient?**

   c) Learning how to do modeling and experimentation is easier on simple systems.

   d) Hence, in this class we do experiments on pendula, not with particle accelerators.

What is Science?

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As Neils Bohr famously said,

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Scientific Method:

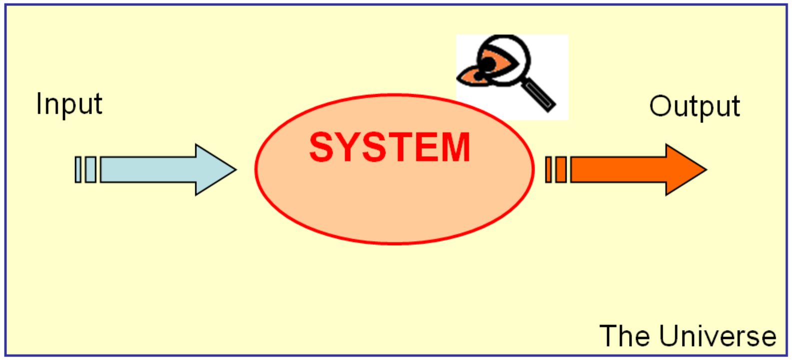
Leads to ***new discoveries*** → how scientific progress is made!

Careful measurements, Experiments

Models, Empirical Laws, Generalization

Hypothesis, Theory

Testing a Model?



- Steps in a Scientific Investigation [Baird, Ch. 5-3]
  - Clearly Identify:
    - The problem or question or interaction to be addressed.
    - The system to study and its boundaries.
    - The significant variables in observation—key is to set up experiment with isolated input and output variable(s)
  - Develop a model of the system—key is to quantitatively describe interaction of inputs with system (see below).
  - Test the model through experimentation—key to designing experiment is whether data will allow quantitative evaluation of model for given input variable(s) and output variable(s) [see Baird, Ch. 5 on Experimental Design]
  - Evaluate the model as a description of the system—key is to know how good is "good enough" and how to test this quantitatively [see Baird Ch. 6 on Experiment Evaluation]
  - Refine the model to cover:
    - More precise measurements
    - More general conditions
- Basic approach to develop and evaluate the usefulness of a model [Baird, Ch 4.1].
  - Know data and uncertainties (presumably)
  - Use this to identify system, inputs and outputs
  - Now develop a model
  - Then test model by comparison with data (first qualitatively, then quantitatively)

Intermediate Lab

PHYS 3870

The principle of science, the definition, almost, is the following: The test of all knowledge is experiment. Experiment is the sole judge of scientific "truth." But what is the source of knowledge? Where do the laws that are to be tested come from? Experiment, itself, helps to produce these laws, in the sense that it gives us hints. But also needed is imagination to create from these hints the great generalizations-to guess at the wonderful, simple, but very strange patterns beneath them all. and then to experiment to check again whether we have made the right guess.

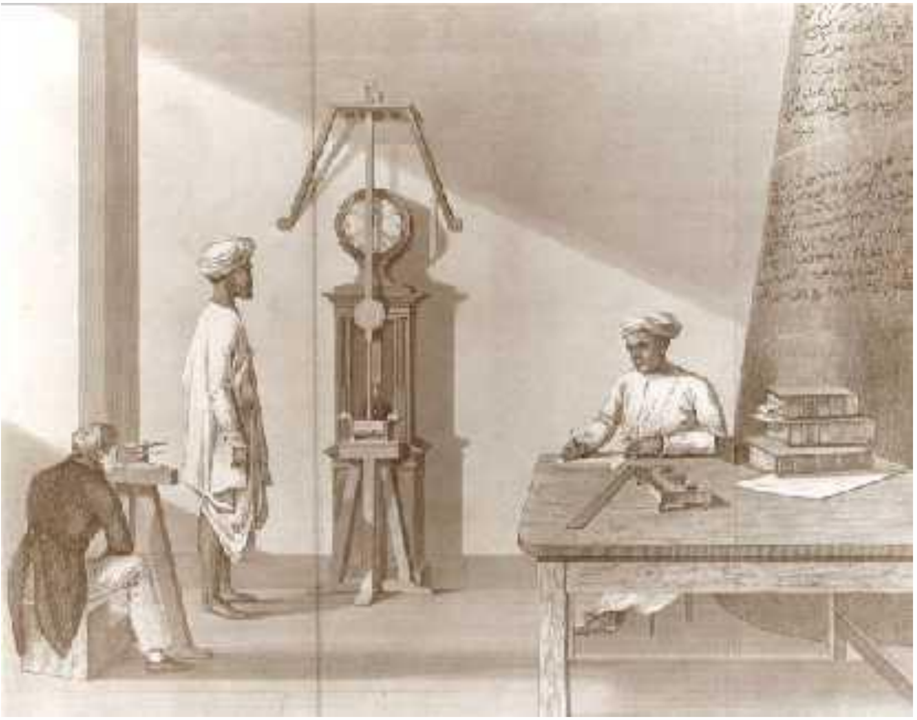
–R. P. Feynman

The Feynman Lectures on Physics (Addison-Wesley, Read-ing, MA, 1963), Vol.1, Chap. I.

Design of Experiments to Study Specific Aspects of a Problem

Pendulum Labs

Simple Pendulum (PHYS 2220)
Physical (Kater) Pendulum
Compound (Wilberforce) Pendulum
Cavendish Balance
Chaotic Pendula



Kater, H., Phil. Trans., 108, 33 (1818).

- **Measured "little g" to a few ppm.**
- **Became the defining standard for the British "yard".**
- **Vastly improved geodetic surveying accuracies.**

Focus of Experiment

Length standard
Materials properties
Measuring "little g"
Measuring "big G"
Gravitational anomalies (fifth force?)
Shape of orbits or the Earth
Coupling of forces

Historical Perspective on Gravity

Cavendish

Developed a clever way to measure the weak gravitational force between small masses.

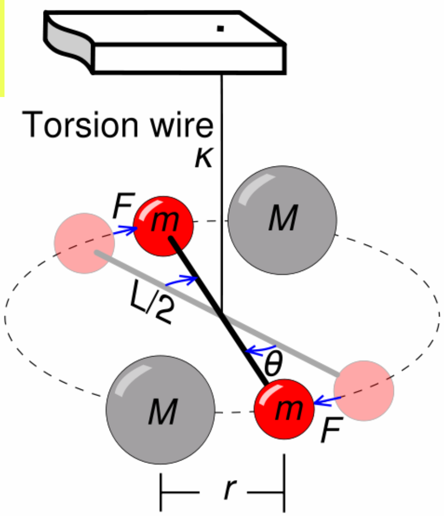
Confirmed Newton's Law of Universal Gravitation (and in essence measured the mass of the Earth in comparison to the kg mass standard).

The effect the 320 kg balls on the 1.5 kg balls was about that of a grain of sand!

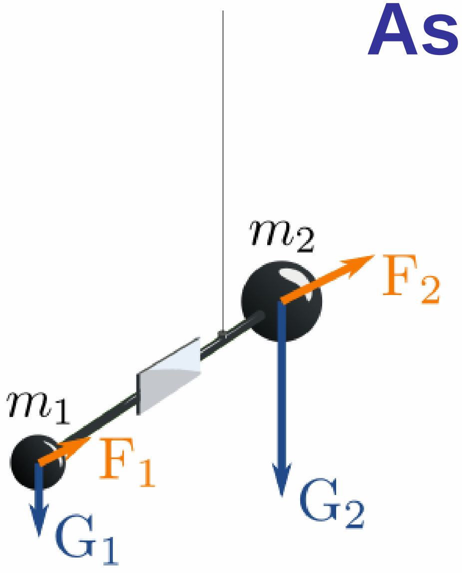
That's 20 parts per billion precision!!!

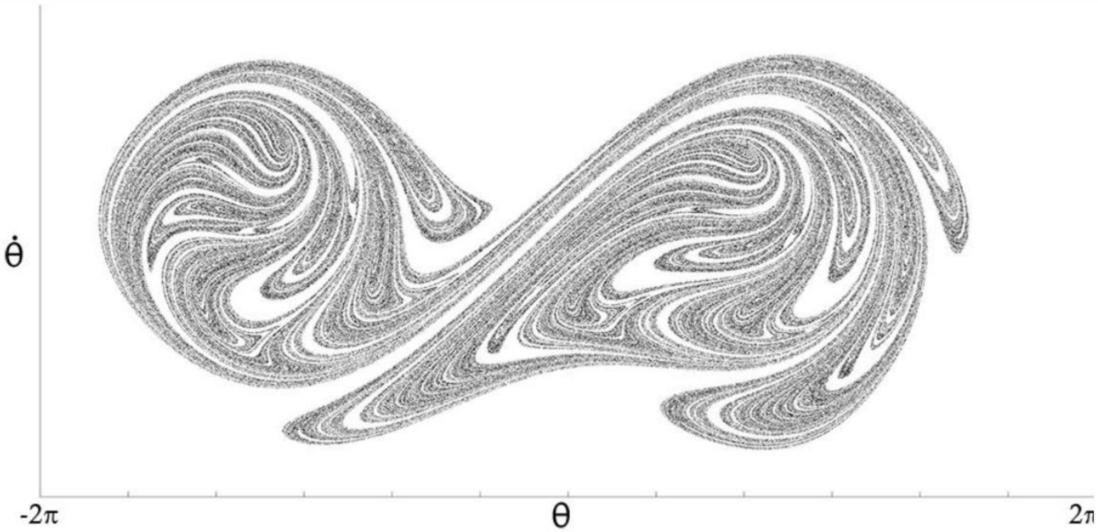
Wikeapedia has a nice description of the experiment.

$$\mathbf{F}_{gravity} = \frac{GmM_{earth}}{r^2}$$



Design of Experiments to Study Specific Aspects of a Problem





Eötvös and Fishback

Correlation between inertial mass and gravitational mass

Gravitational anomalies (fifth force?)

The original Eötvös data of these ~1880's experiments were re-examined , including detailed studies of the local stratigraphy, the physical layout of the Physics Institute (which Eötvös had personally designed), and even the weather and other effects. The experiment is therefore well recorded.

Chaotic Pendula