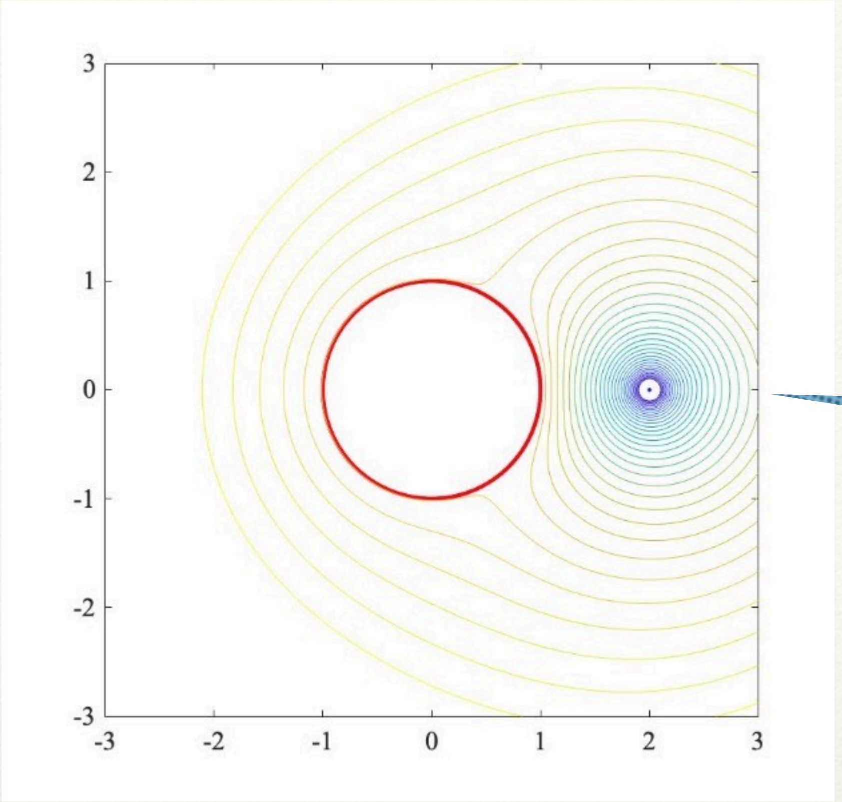


Faraday cage electrostatic shielding cast as a constrained optimization problem, and how Feynman was "wrong."

1st year physics with MATLAB

Duncan Carlsmith, SERC, Oct 2020

1st-year computational curriculum

- **What**: Physics 247-8, Introductory Physics using MATLAB, 5-cr, 2-sem, automatic honors, for ~80 first year Physics, Astronomy, and Applied Math Engineering and Physics (AMEP) students
- **How**: Tutorials with Live Scripts and integrated MATLAB analysis of laboratory data.
- **Topics**: Modeling, simulation, visualization, signal analysis, numerical techniques, symbolic algebra, intermediate and advanced mathematics, probability and statistics, and statistical analysis and interpretation of data.
- **Why**: A foundation for computation throughout the undergraduate physics curriculum.

Learning goals

- Understand and apply principles of physics…
- Innovate and apply.
- Own measurements and analysis.
- Understand and apply hardware and software technologies.
- Discover and use current research and open data.
- Think computationally and scientifically (model, test…).
- Collaborate and communicate!

1st semester syllabus

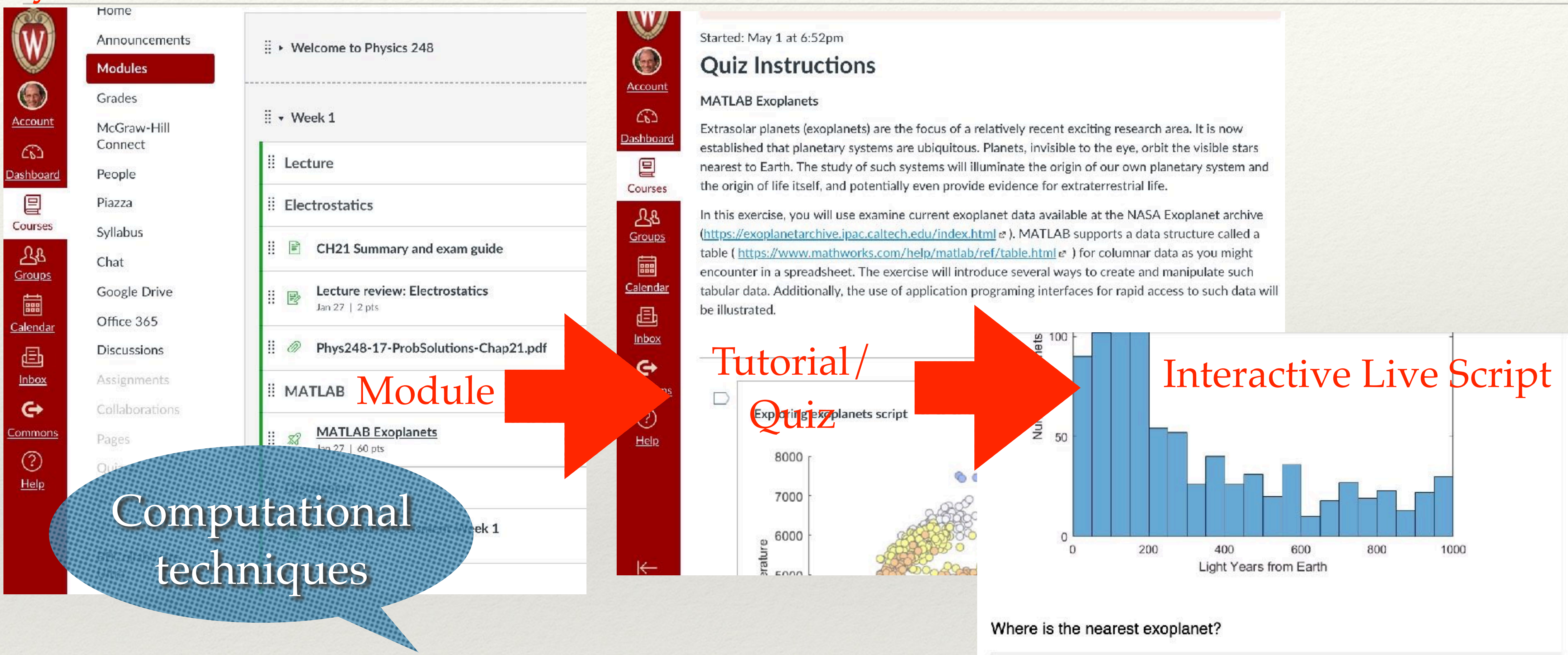
Week	Mon	MATLAB assignment Tutorial	Lab M 1:20 601, T 1:20 602, W 2:25 603, R 1:20 604 CH4136 Lab	Wed	Disc: W 1:20, 2:25 R 1:20, 2:25 Chamberlin 2104	Fri
1	no class	MATLAB onramp, MATLABGetting Started with MATLAB, MATLAB Introduction to MATLAB, MATLAB Image processing	No lab UW Instruction begins	Measurement, Ch. 1	Ch. 1,2	Motion Along a Straight Line Ch. 2
2	Vectors Ch. 3	MATLAB Concepts in probability,	Computer vision	Motion in 2 and 3 dimensions Ch. 4	Ch. 3,4	Motion in 2 and 3 dimensions Ch. 4
3	Force and Motion I Ch. 5	MATLAB quiver plot, MATLAB More concepts in probability	Acceleration and free fall	Force and Motion II Ch. 6	Ch. 5,6	Force and Motion II Ch. 6
4	Kinetic Energy and Work Ch 7	No MATLAB	No lab	Kinetic Energy and Work Ch 7	Ch. 6,7	Exam 1, CH1-6
5	Potential Energy and Energy Conservation Ch. 8	MATLAB Curve fitting	Computation and modeling	Potential Energy and Energy Conservation Ch.	Ch. 8,9	Center of Mass and Linear momentum Ch. 9
6	Center of Mass and Linear Momentum Ch. 9	MATLAB StackedBallCollisions	Inertial sensors	Relativity Ch. 37	Ch. 37	Relativity Ch. 37
7	Quarks, Leptons, and the Big Bang Ch. 44	MATLAB dubugging	Particle physics	Quarks, Leptons, and the Big Bang Ch. 44	Ch. 44	Rotation Ch. 10
8	Rotation Ch. 10	No MATLAB	No lab, formal lab report 1 due	Rolling, torque, and angular momentum Ch. 11	Ch. 9,10	Exam 2, CH6-9,37,44
9	Rolling, torque, and angular momentum Ch. 11	MATLAB Black Holes	Cosmic muons and radioactivity	Equilibrium Ch. 12	Ch. 11,12	Gravitation Ch. 13
10	Gravitation Ch. 13	MATLAB Ephemerides	Asteroids and bombs	Fluids Ch. 14	Ch. 13,14	Fluids Ch. 14
11	Oscillations Ch. 15	MATLAB Fit parametric curves	Simple harmonic oscillator and resonance	Oscillations Ch. 15	Ch. 15	Waves I Ch. 16
12	Waves I Ch. 16	No MATLAB	Standing waves on a string	Waves II Ch. 17	Ch. 16,17	Exam 3, CH10-15
13	Waves II Ch. 17	No MATLAB	No lab, formal lab report 2	Temperature, Heat and the first law of	Thanksgiving	Thanksgiving
14	Temperature, Heat and the first law of Thermodynamics	MATLAB LIGO Analysis	Acoustics and Doppler shift	The Kinetic Theory of Gases Ch. 19	Ch. 18,19	The Kinetic Theory of Gases Ch. 19
15	Entropy and the 2nd Law of Thermodynamics	MATLAB Exoplanets	No lab	Entropy and the 2nd Law of Thermodynamics	Ch. 20	Exam study period
						Exam 4, Ch 16-20 12/12/20, Saturday, 10:05AM - 12:05PM

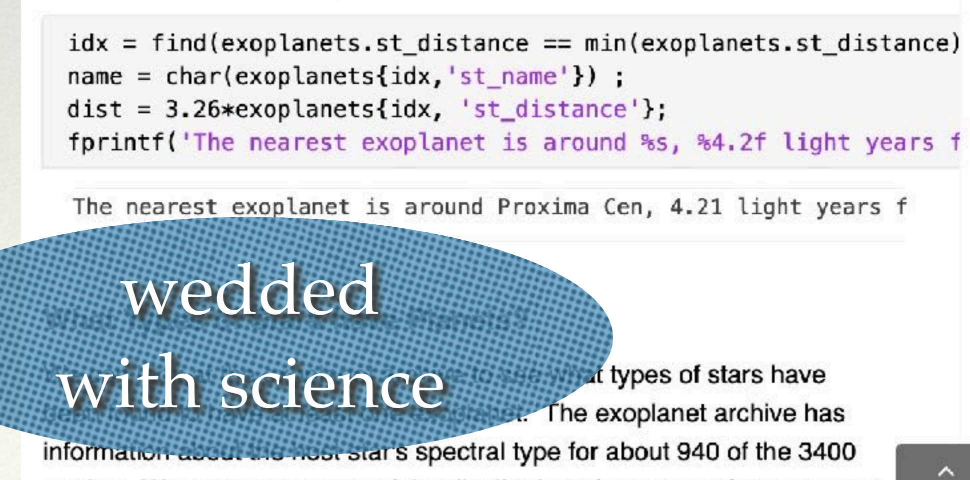
2nd semester syllabus

Week	Mon	MATLAB lab	Lab M or T 1:20-4:15 W 2:25-5:20,CH3136 Prelab	Wed	Disc: R 1:20 2:25, 3:30	Fri
1	no class	Tutorial	Lab	Coulomb's Law, Ch. 21	Group and challenge	Coulomb's Law, Ch. 21
2	Electric Fields, Ch. 22	MATLAB Vectors and rotations	Electric Fields	Electric Fields, Ch. 22	Group and challenge	Gauss' Law, Ch. 23
3	Gauss' Law, Ch. 23	Matlab Electric fields and potentials	Magnetic field map	Electric Potential, Ch. 24	Group and challenge	Electric Potential, Ch. 24
4	Capacitance, Ch. 25	MATLAB Electrostatic induction (and the	Oscilloscopes and RC circuits	Capacitance, Ch. 25	Group and challenge	Current and Resistance, Ch. 26
5	Current and Resistance, Ch. 26	MATLAB Method of images	Electron charge to mass ratio	Circuits, Ch. 27	Group and challenge	Circuits, Ch. 27
6	Magnetic Fields, Ch. 28	MATLAB Vector Calculus	No lab	Magnetic Fields, Ch.28	Group and challenge	Exam 1, CH 21-26
7	Magnetic Fields Due to Currents,	MATLAB Magnetic field of a coil	Magnetic induction	Magnetic Fields Due to Currents, Ch.	Group and challenge	Induction and Inductance, Ch. 30
8	Induction and Inductance, Ch. 30	MATLAB World's simplest electric train	LRC Circuit and Resonance	Electromagnetic Oscillations and	Group and challenge	Electromagnetic Oscillations and
9	Spring Break			Spring Break	Spring Break	Spring Break
10	Maxwell's Equations;Magneti	MATLAB ABCD Matrices	Mirrors and lenses	Maxwell's Equations;Magnetis	Group and challenge	Electromagnetic Waves, Ch. 33
11	Electromagnetic Waves, Ch. 33	MATLAB Diffraction	Optical Instruments	Images, Ch. 34	Group and challenge	Images, Ch. 34
12	Interference, Ch. 35	MATLAB Monte Carlo methods	No Lab	Interference, Ch. 35	Group and challenge	Exam 2, CH27-32
13	Diffraction, Ch. 36	MATLAB Bound states	Diffraction and Interference	Diffraction, Ch. 36	Group and challenge	Photons and Matter waves, Ch. 38
14	Photons and Matter waves, Ch.	MATLAB Quantum mechanics	Balmer Series	More About Matter waves, Ch. 39	Group and challenge	More About Matter waves, Ch. 39
15	All About Atoms, Ch. 40	MATLAB Electric field of an accelerated charge - 3d	Speed of light	All About Atoms, Ch. 40	Group and challenge	All About Atoms, Ch. 40

Tutorial: Exoplanets

Physics 248, Week 1

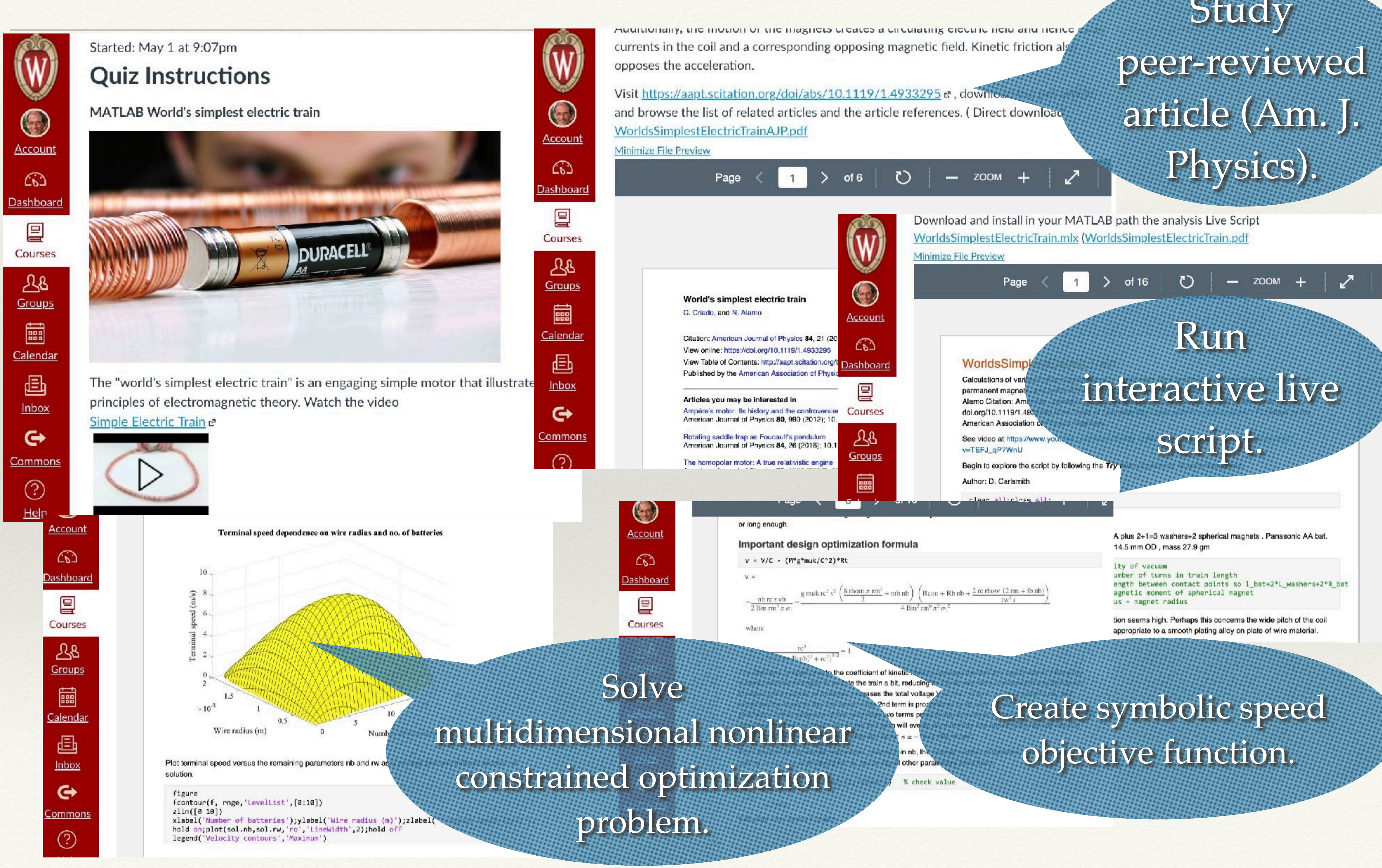




- This example: Access NASA data via direct download, and using an API within MATLAB, to characterize exoplanets and their host systems.

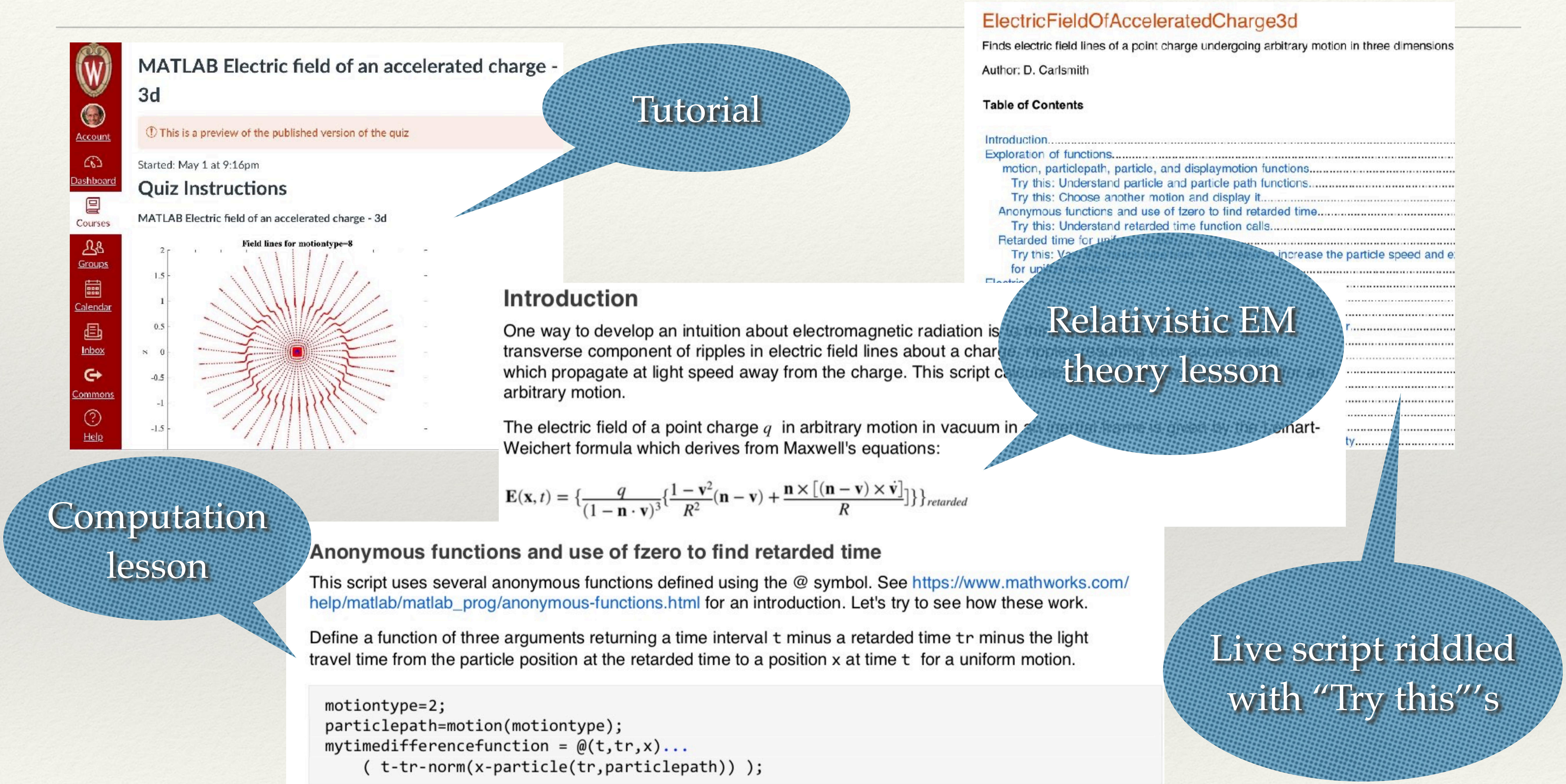
Fuse learning about current, voltage, resistance, permanent magnetism, Biot-Savart with mechanics, Lorentz force, friction, eddy current losses, and computation, all in one cool toy

Tutorial: World's simplest electric train



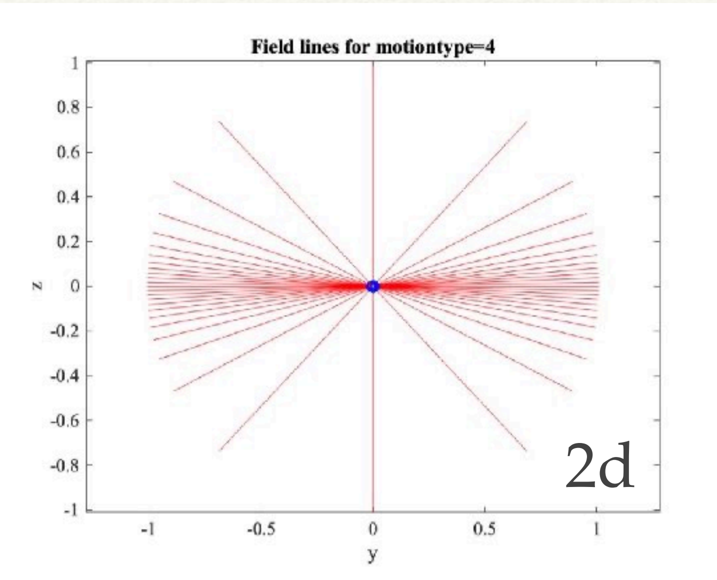
Visualize electromagnetic radiation as transverse component of wiggles in electric field lines flying at light speed.

Tutorial: Radiation from an accelerated charge

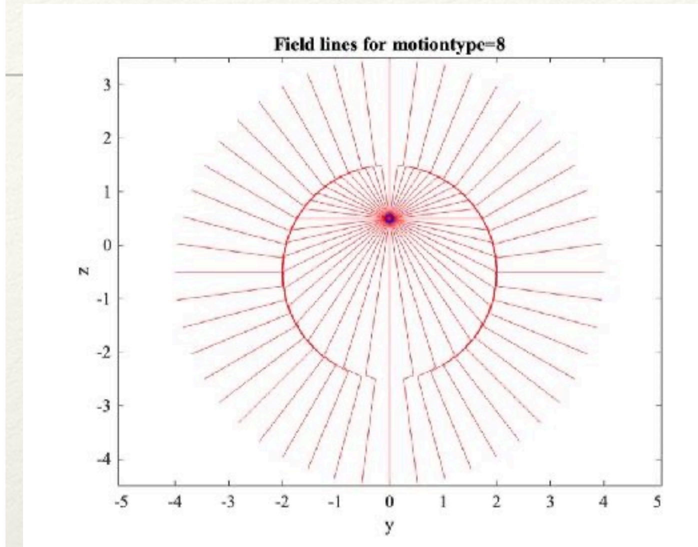


- Find retarded time for any observation point and arbitrary 3d parametrized motion.
- Solve system of ode's for field lines using LW formula given retarded time.

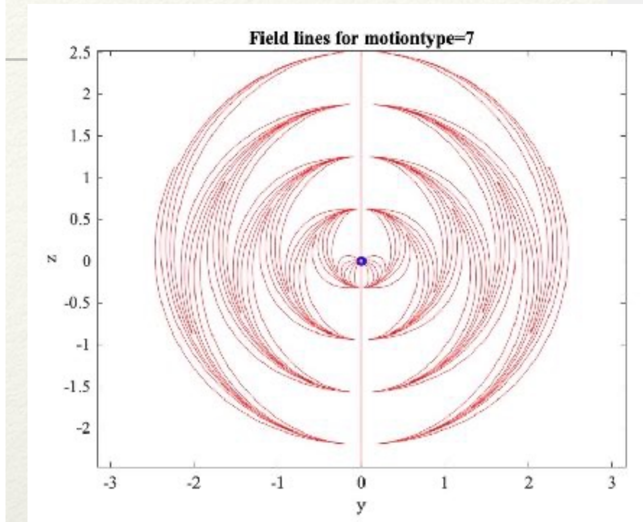
Electric field lines of charge in motion in 3d



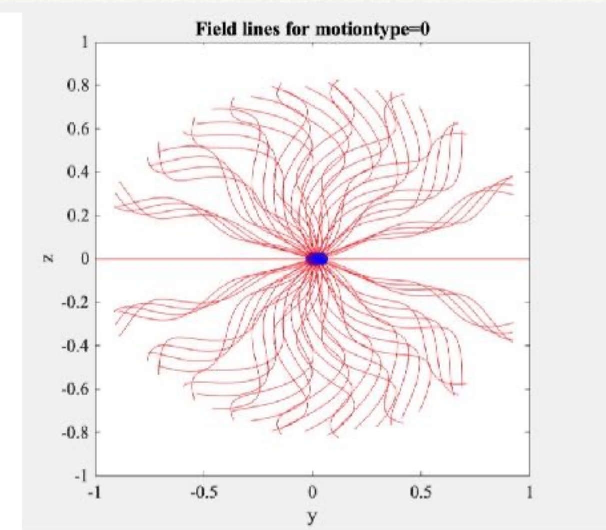
Relativistic uniform motion



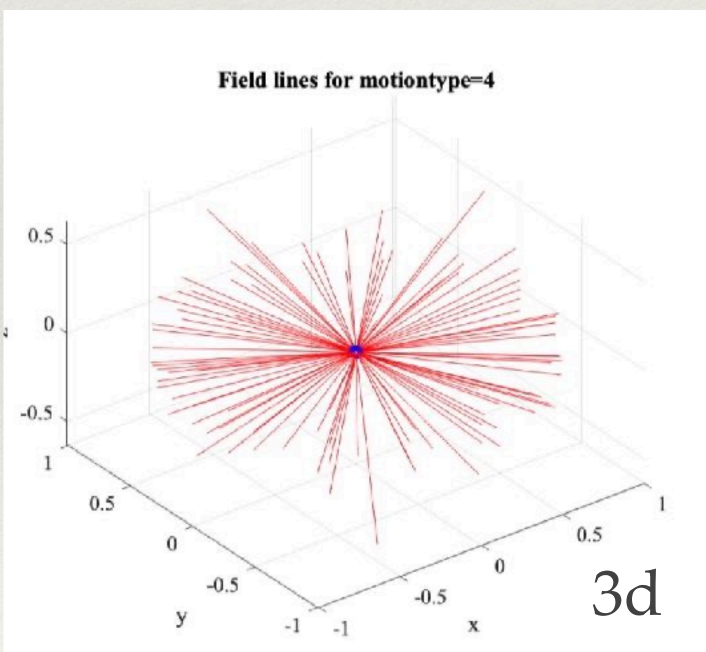
Relativistic impulse



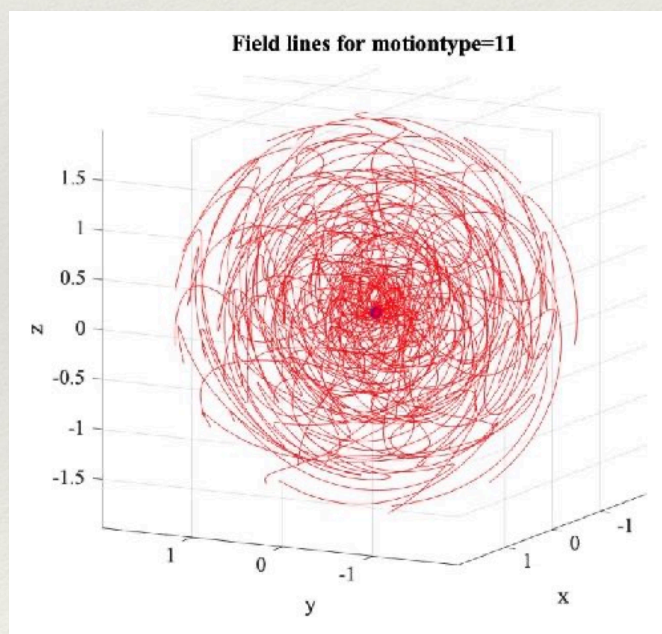
Relativistic oscillator



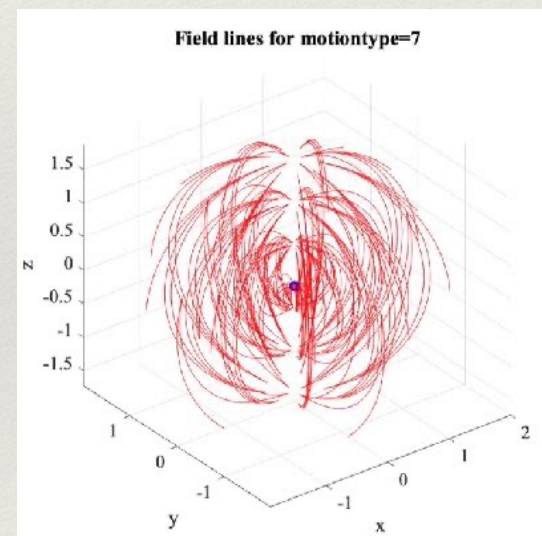
Movies

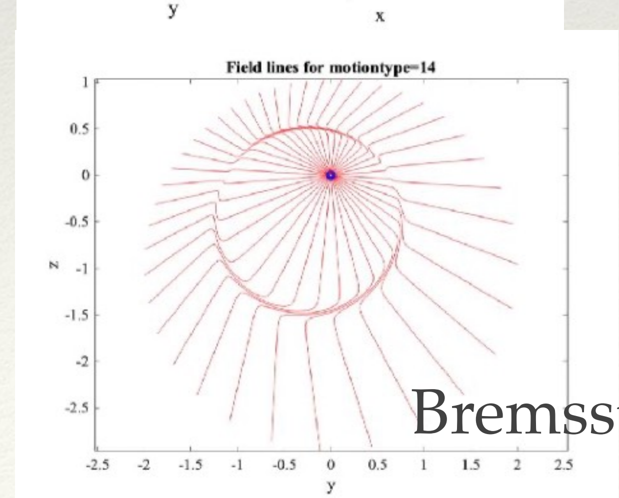


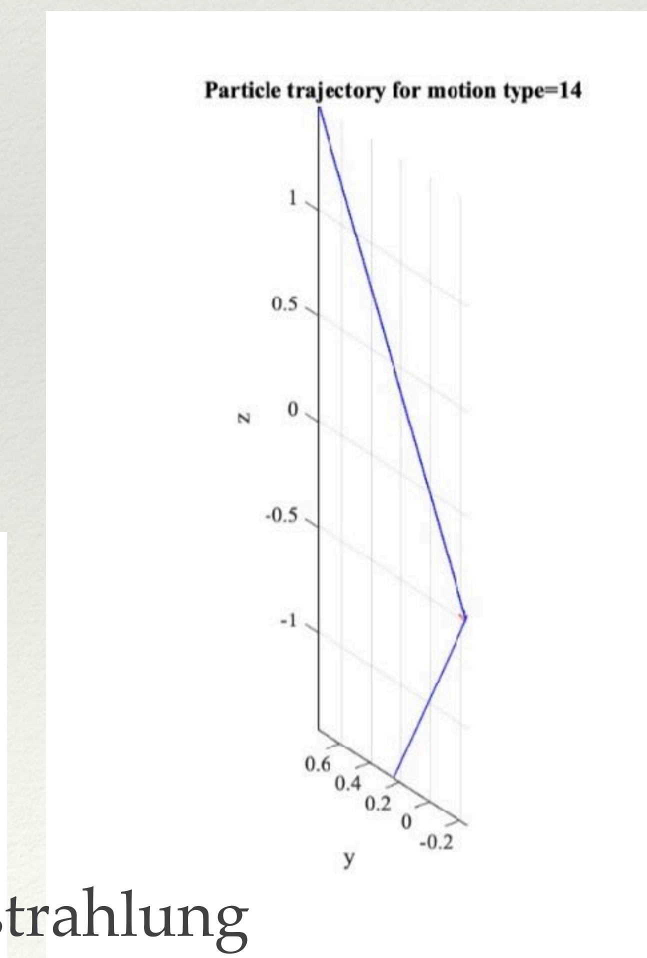
Relativistic uniform motion



Circular motion 3d





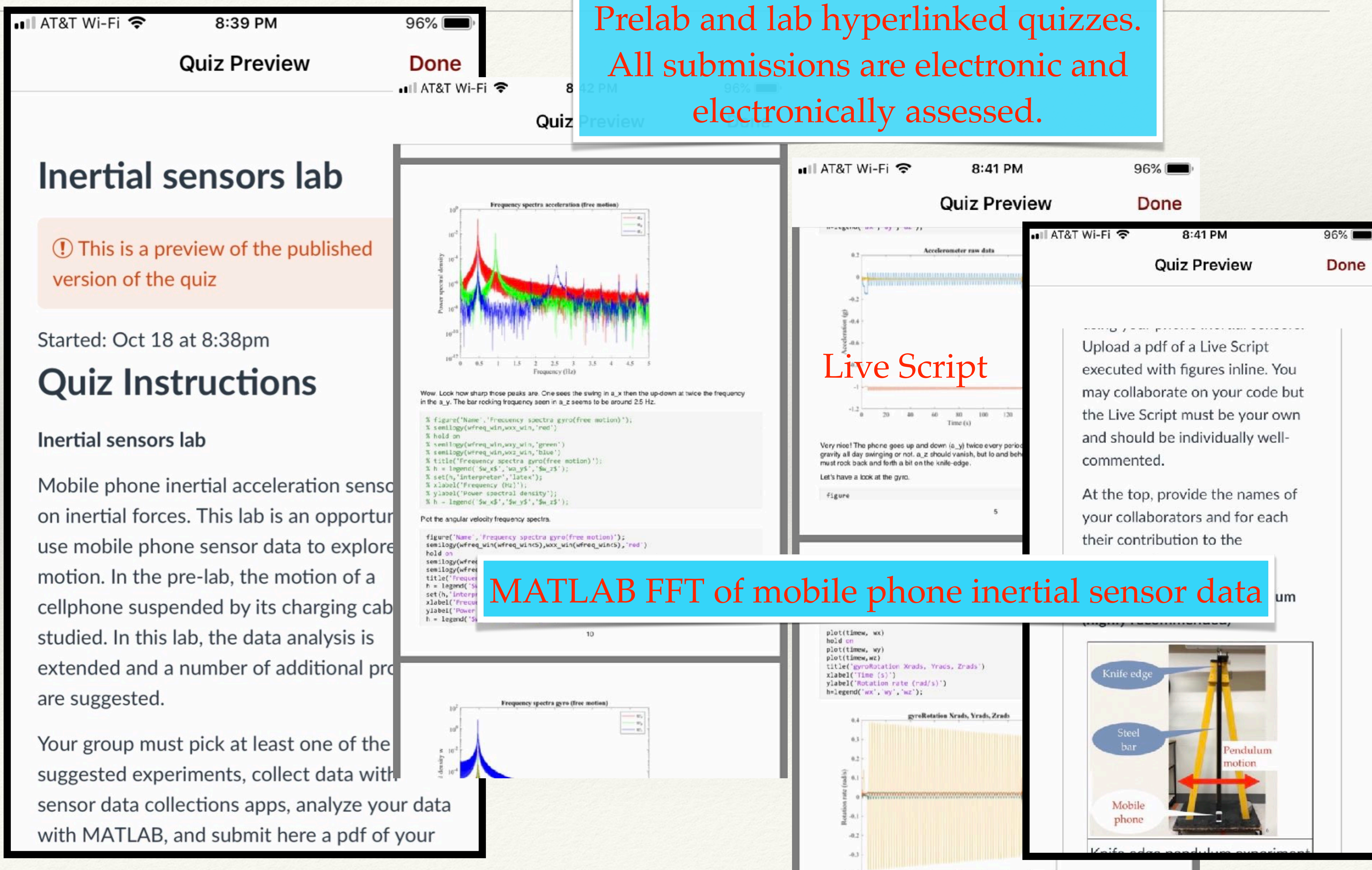


Bremsstrahlung

- Sweet!

Prelab and Lab : Inertial sensors

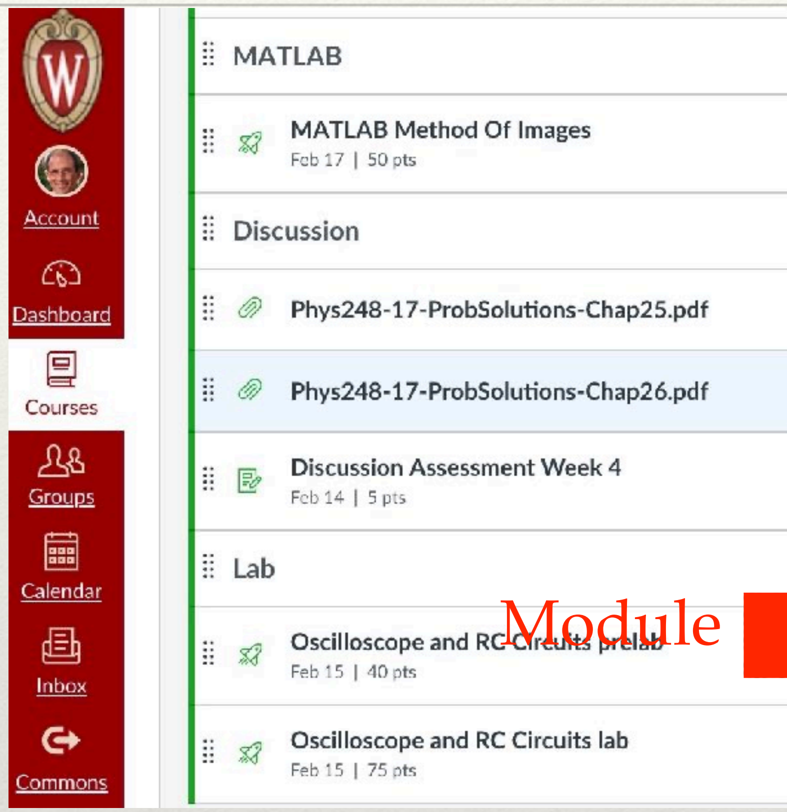
Prelab and lab hyperlinked quizzes. All submissions are electronic and electronically assessed.



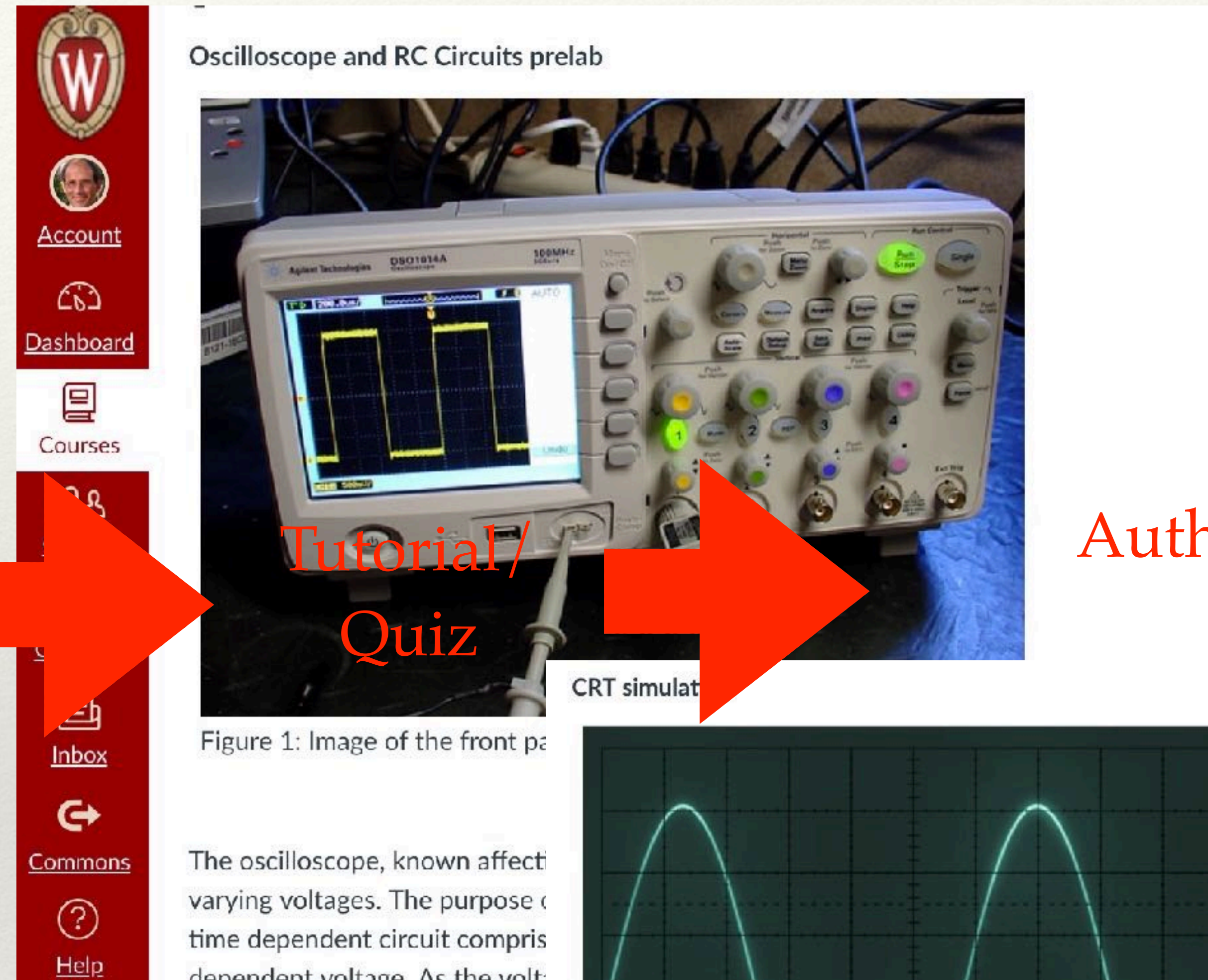
MATLAB FFT of mobile phone inertial sensor data

Pre-lab: Oscilloscope

Physics 248, Week 4ish

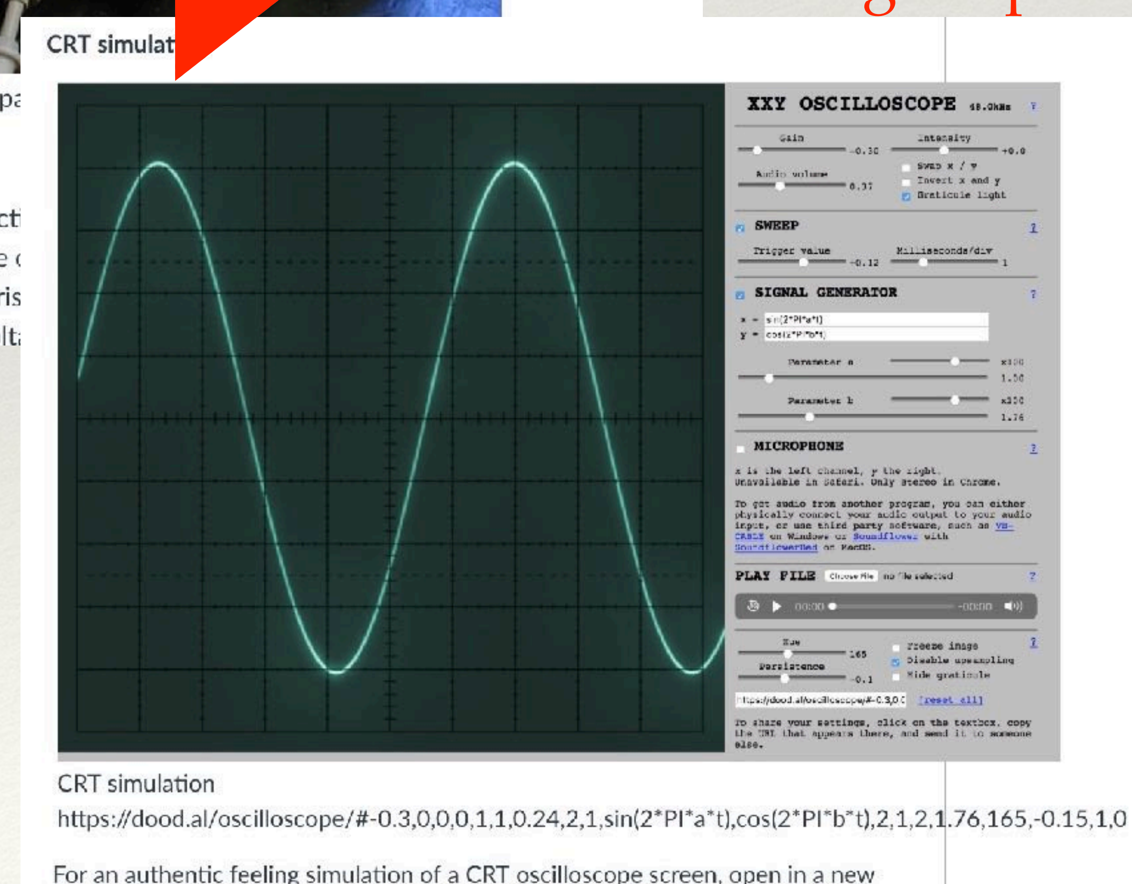


Module



Tutorial/ Quiz

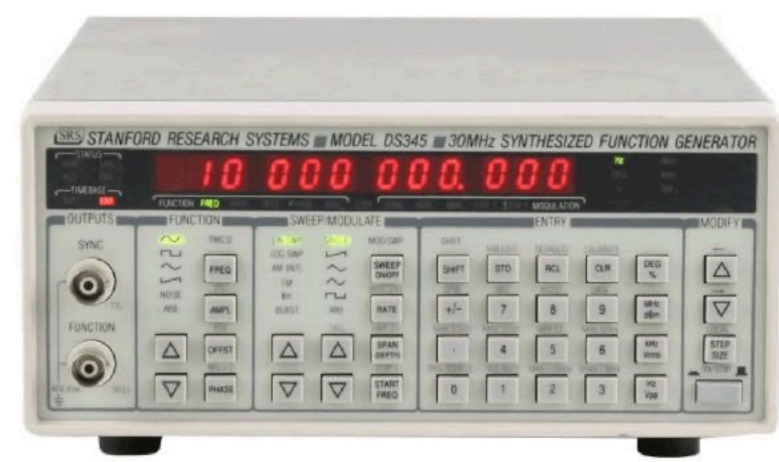
Authentic simulation of analog scope



- Introduction to oscilloscopes.
- Play beforehand and learn about historical technology.

Lab: Oscilloscope

Physics 248, Week 4ish



Study function generator specs and manuals

A function generator (also called signal generator) is designed to supply periodic standard voltage signals into standard electrical loads of 50 Ohms or greater. Typically a sine-wave, square-wave, and triangular wave or ramp wave are selectable from the front panel along with their amplitude and frequency. Download the data sheet for a low cost function generator http://www.testequipmentdepot.com/instek/pdf/sfg1003.pdf and notice the

Account
Dashboard
Courses
Groups
Calendar
Inbox
Commons

MATLAB

MATLAB Method Of Images
Feb 17 | 50 pts

Discussion

Phys248-17-ProbSolutions-Chap25.pdf

Phys248-17-ProbSolutions-Chap26.pdf

Discussion Assessment Week 4
Feb 14 | 5 pts

Lab

Module

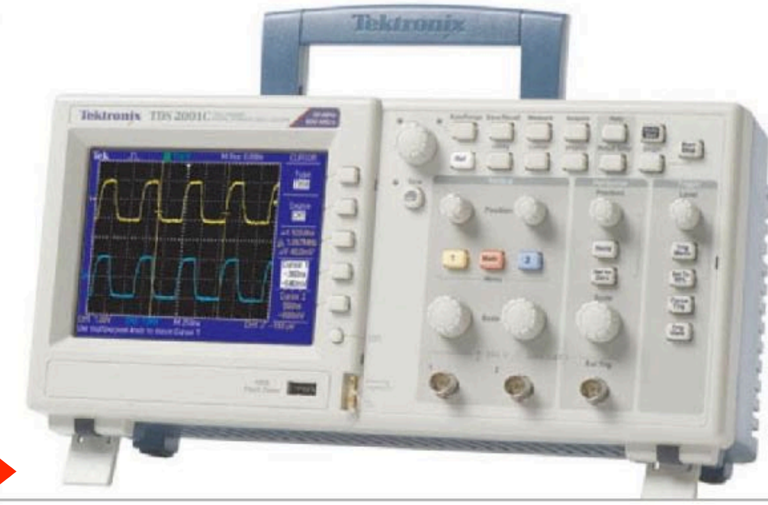
Oscilloscope and RC Circuits prelab
Feb 15 | 40 pts

Oscilloscope and RC Circuits lab
Feb 15 | 75 pts

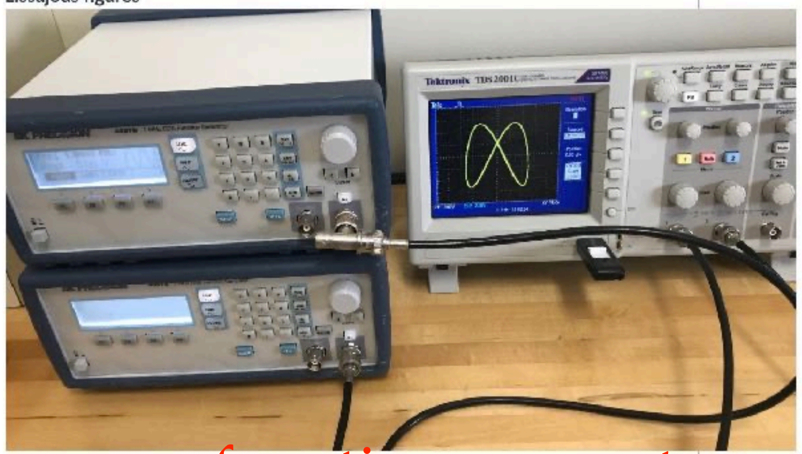
Quiz Instructions

Oscilloscope and RC circuits lab

Lab



Lissajous figures



Study digital scope specs and manuals

Compare function generators

Download TDS2001c specifications

It is always important to understand the specifications of your equipment. Visit the manufacturer's site http://www.testequipmentdepot.com/tektronix/oscilloscope/tds2001c.htm and download the data sheet for this representative oscilloscope. The direct link is http://www.testequipmentdepot.com/tektronix/pdf/tds2000c_data.pdf . The scope you will use in this lab is similar to this one. Find in the data sheet the input impedance of the scope. It will likely be specified as an equivalent resistance in parallel with a capacitance. The capacitance will short out frequencies higher than about 1/RC.

Question 11 — 10 pts

UW-Libraries
https://ezproxy.library.wisc.edu/login?url=%27...

RC circuit and capacitors in series and parallel

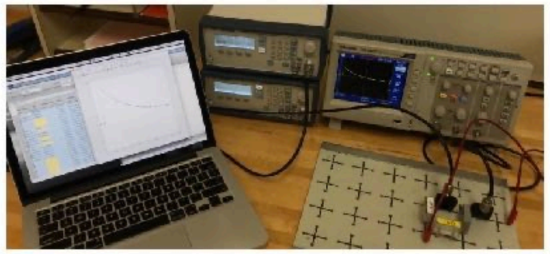


Figure 1: Setup for observing a series RC circuit

If a resistor and capacitor are connected in series and the pair driven by a function generator square wave with voltage oscillating between zero and a value A and with period long compared to the characteristic time $\tau = RC$, the voltage V between the resistor and capacitor will not follow the square wave precisely. Instead, starting at the rising edge of the square wave, the voltage V will approach A exponentially with time constant τ, and, starting at the falling edge, the voltage V will approach zero with the same time constant.

Connect in series a resistance of order 1 kOhm and a capacitance of order 1 microfarad so $\tau \simeq 1$ ms, and drive the pair with the function generator with a square wave of period of order 10 ms and amplitude of 5 V. A breadboard setup is

Extract and fit scope data on RC circuit response on laptop with MATLAB. Own it!

- Introduction to oscilloscope and RC circuits

Oscilloscope and RC Circuits lab

Question 2

TDS2001C sample rate

The TDS2001C digital oscilloscope samples the value of the input voltage and digitizes the samples with 8-bit accuracy. A sample rate of 1 GS/s (1 Giga Samples/second) would correspond to one sample every nanosecond. What is the sample rate indicated in the data sheet?

Correct!

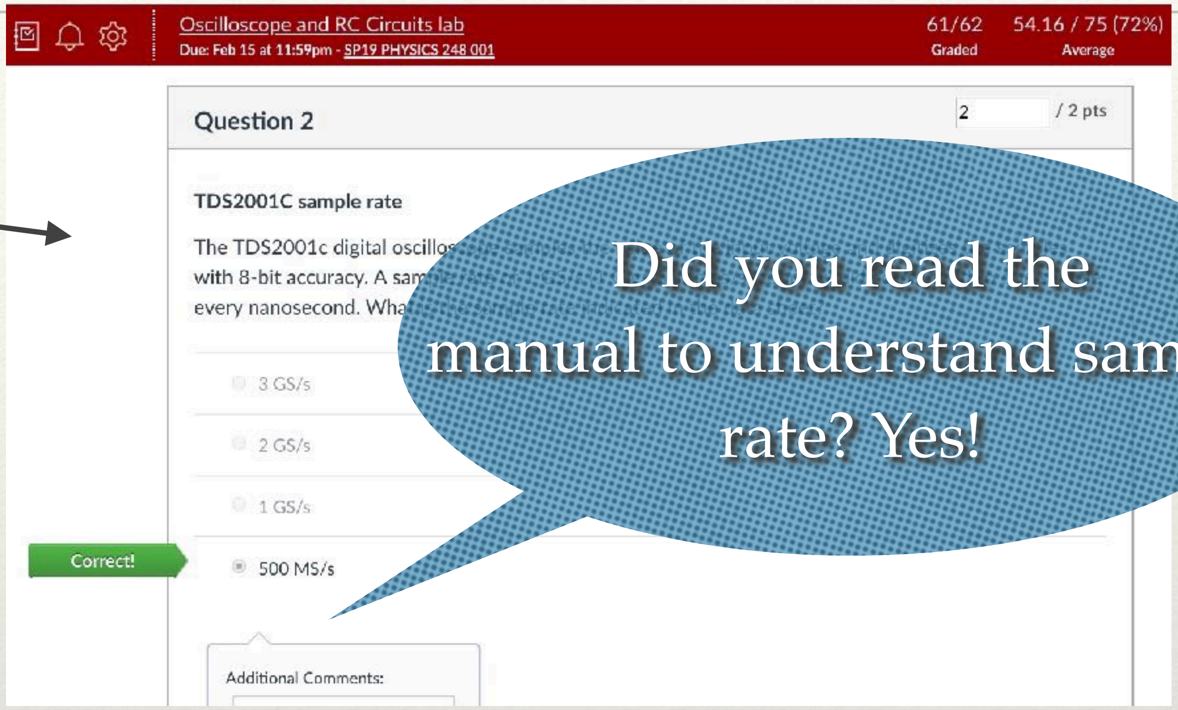
Question 1 — 2 pts

TDS2001c specification: maximum input voltage

What is the maximum input voltage of the TDS 2001c according to the data sheet?

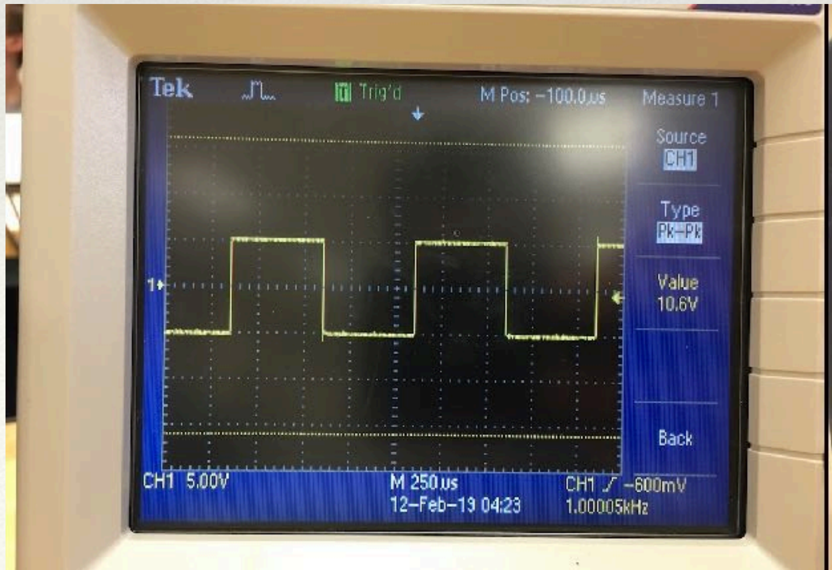
Lab assessment

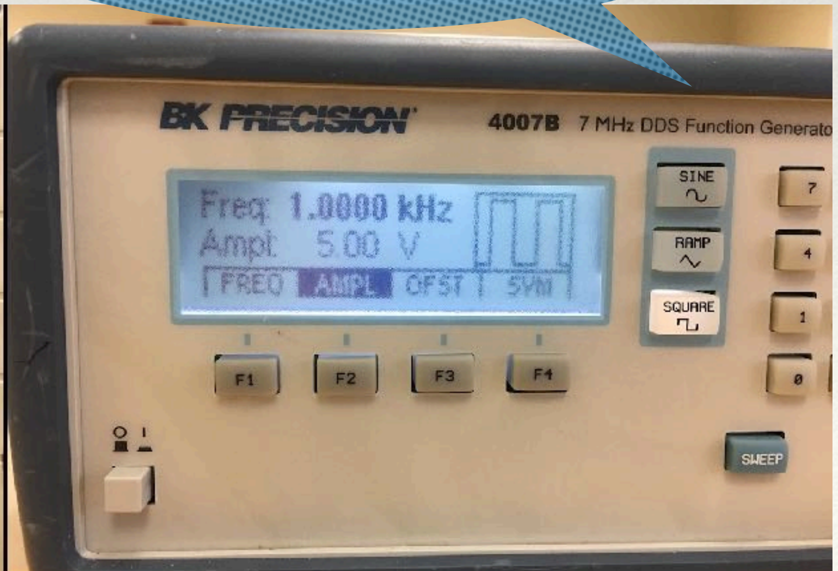
- Autograded baseline questions
- Phone photos
- Text
- Plots
- Tables
- Live scripts

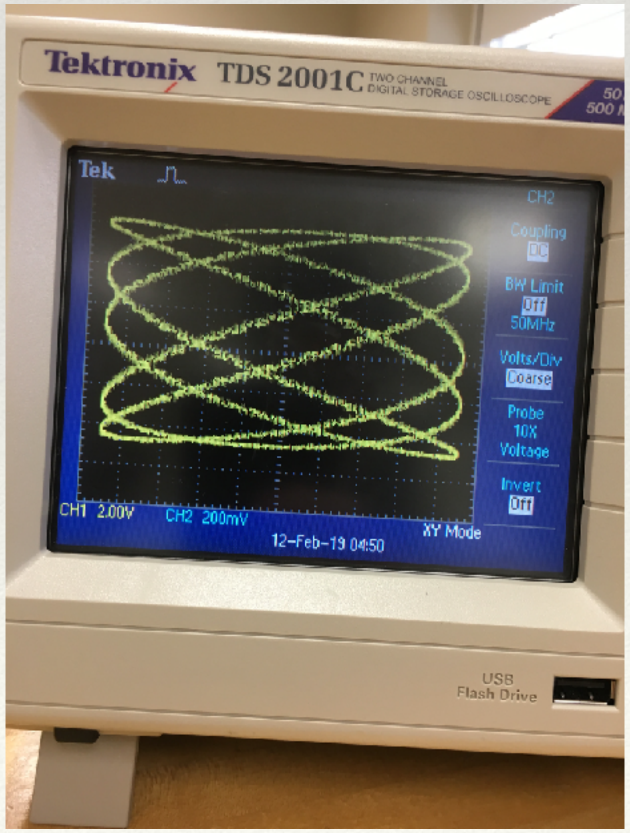


Did you read the manual to understand sample rate? Yes!

Example student photo submissions

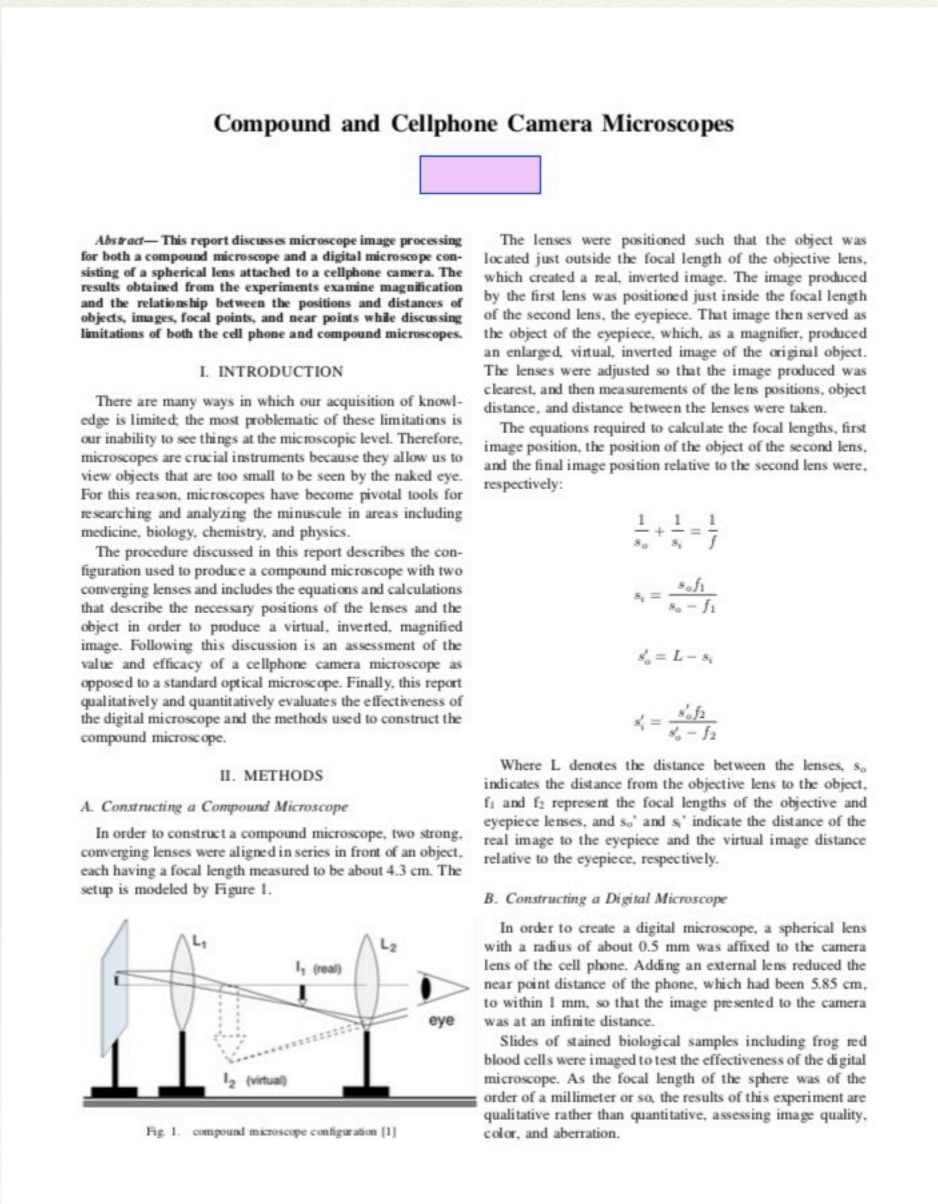






Journal style lab reports

- Journal style lab reports, in addition to submitted plots and live scripts



Compound and Cellphone Camera Microscopes

[redacted]

Abstract— **This report discusses microscope image processing for both a compound microscope and a digital microscope consisting of a spherical lens attached to a cellphone camera. The results obtained from the experiments examine magnification and the relationship between the positions and distances of objects, images, focal points, and near points while discussing limitations of both the cell phone and compound microscopes.**

I. INTRODUCTION

There are many ways in which our acquisition of knowledge is limited; the most problematic of these limitations is our inability to see things at the microscopic level. Therefore, microscopes are crucial instruments because they allow us to view objects that are too small to be seen by the naked eye. For this reason, microscopes have become pivotal tools for researching and analyzing the minuscule in areas including medicine, biology, chemistry, and physics.

The procedure discussed in this report describes the configuration used to produce a compound microscope with two converging lenses and includes the equations and calculations that describe the necessary positions of the lenses and the object in order to produce a virtual, inverted, magnified image. Following this discussion is an assessment of the value and efficacy of a cellphone camera microscope as opposed to a standard optical microscope. Finally, this report qualitatively and quantitatively evaluates the effectiveness of the digital microscope and the methods used to construct the compound microscope.

II. METHODS

A. Constructing a Compound Microscope

In order to construct a compound microscope, two strong, converging lenses were aligned in series in front of an object, each having a focal length measured to be about 4.3 cm. The setup is modeled by Figure 1.

Fig. 1. compound microscope configuration [1]

The lenses were positioned such that the object was located just outside the focal length of the objective lens, which created a real, inverted image. The image produced by the first lens was positioned just inside the focal length of the second lens, the eyepiece. That image then served as the object of the eyepiece, which, as a magnifier, produced an enlarged, virtual, inverted image of the original object. The lenses were adjusted so that the image produced was clearest, and then measurements of the lens positions, object distance, and distance between the lenses were taken.

The equations required to calculate the focal lengths, first image position, the position of the object of the second lens, and the final image position relative to the second lens were, respectively:

$$\frac{1}{s_o} + \frac{1}{s_i} = \frac{1}{f}$$

$$s_i = \frac{s_o f_1}{s_o - f_1}$$

$$s_o' = L - s_i$$

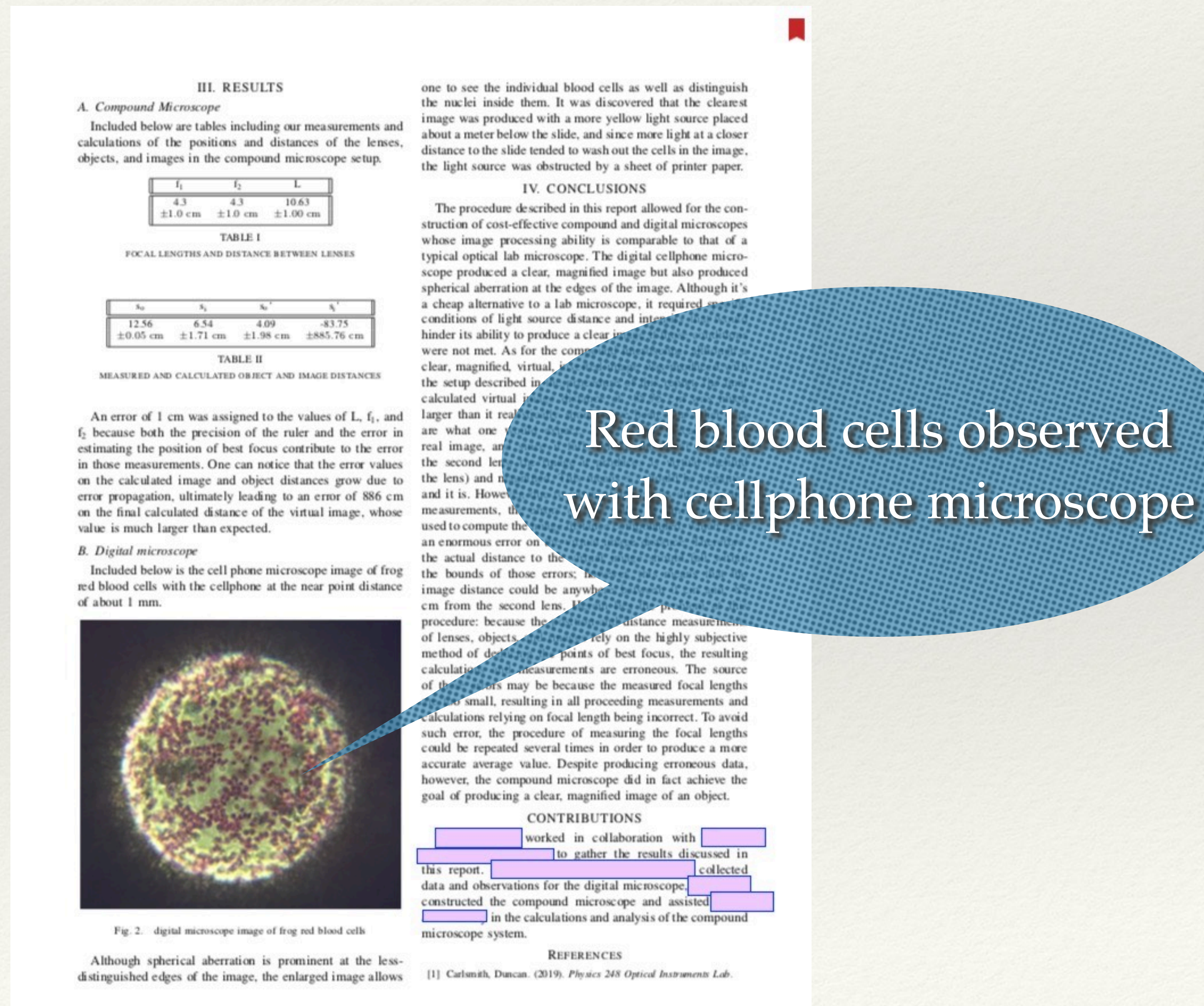
$$s_i' = \frac{s_o' f_2}{s_o' - f_2}$$

Where L denotes the distance between the lenses, s_o indicates the distance from the objective lens to the object, f_1 and f_2 represent the focal lengths of the objective and eyepiece lenses, and s_o' and s_i' indicate the distance of the real image to the eyepiece and the virtual image distance relative to the eyepiece, respectively.

B. Constructing a Digital Microscope

In order to create a digital microscope, a spherical lens with a radius of about 0.5 mm was affixed to the camera lens of the cell phone. Adding an external lens reduced the near point distance of the phone, which had been 5.85 cm, to within 1 mm, so that the image presented to the camera was at an infinite distance.

Slides of stained biological samples including frog red blood cells were imaged to test the effectiveness of the digital microscope. As the focal length of the sphere was of the order of a millimeter or so, the results of this experiment are qualitative rather than quantitative, assessing image quality, color, and aberration.



III. RESULTS

A. Compound Microscope

Included below are tables including our measurements and calculations of the positions and distances of the lenses, objects, and images in the compound microscope setup.

f_1	f_2	L
4.3 ±1.0 cm	4.3 ±1.0 cm	10.63 ±1.00 cm

TABLE I

FOCAL LENGTHS AND DISTANCE BETWEEN LENSES

s_o	s_i	s_o'	s_i'
12.56 ±0.05 cm	6.54 ±1.71 cm	4.09 ±1.98 cm	-83.75 ±885.76 cm

TABLE II

MEASURED AND CALCULATED OBJECT AND IMAGE DISTANCES

An error of 1 cm was assigned to the values of L, f_1, and f_2 because both the precision of the ruler and the error in estimating the position of best focus contribute to the error in those measurements. One can notice that the error values on the calculated image and object distances grow due to error propagation, ultimately leading to an error of 886 cm on the final calculated distance of the virtual image, whose value is much larger than expected.

B. Digital microscope

Included below is the cell phone microscope image of frog red blood cells with the cellphone at the near point distance of about 1 mm.

Fig. 2. digital microscope image of frog red blood cells

Although spherical aberration is prominent at the less-distinguished edges of the image, the enlarged image allows one to see the individual blood cells as well as distinguish the nuclei inside them. It was discovered that the clearest image was produced with a more yellow light source placed about a meter below the slide, and since more light at a closer distance to the slide tended to wash out the cells in the image, the light source was obstructed by a sheet of printer paper.

IV. CONCLUSIONS

The procedure described in this report allowed for the construction of cost-effective compound and digital microscopes whose image processing ability is comparable to that of a typical optical lab microscope. The digital cellphone microscope produced a clear, magnified image but also produced spherical aberration at the edges of the image. Although it's a cheap alternative to a lab microscope, it required [illegible] conditions of light source distance and inte[illegible] hinder its ability to produce a clear i[illegible] were not met. As for the com[illegible] clear, magnified, virtual, [illegible] the setup described in [illegible] calculated virtual [illegible] larger than it real[illegible] are what one [illegible] real image, an[illegible] the second len[illegible] the lens) and n[illegible] and it is. Howe[illegible] measurements, th[illegible] used to compute the [illegible] an enormous error on [illegible] the actual distance to the [illegible] the bounds of those errors; [illegible] image distance could be anywh[illegible] cm from the second lens. [illegible] procedure: because the [illegible] distance measurements of lenses, objects, [illegible] rely on the highly subjective method of de[illegible] points of best focus, the resulting calculatio[illegible] measurements are erroneous. The source of th[illegible]rs may be because the measured focal lengths [illegible] small, resulting in all proceeding measurements and calculations relying on focal length being incorrect. To avoid such error, the procedure of measuring the focal lengths could be repeated several times in order to produce a more accurate average value. Despite producing erroneous data, however, the compound microscope did in fact achieve the goal of producing a clear, magnified image of an object.

CONTRIBUTIONS

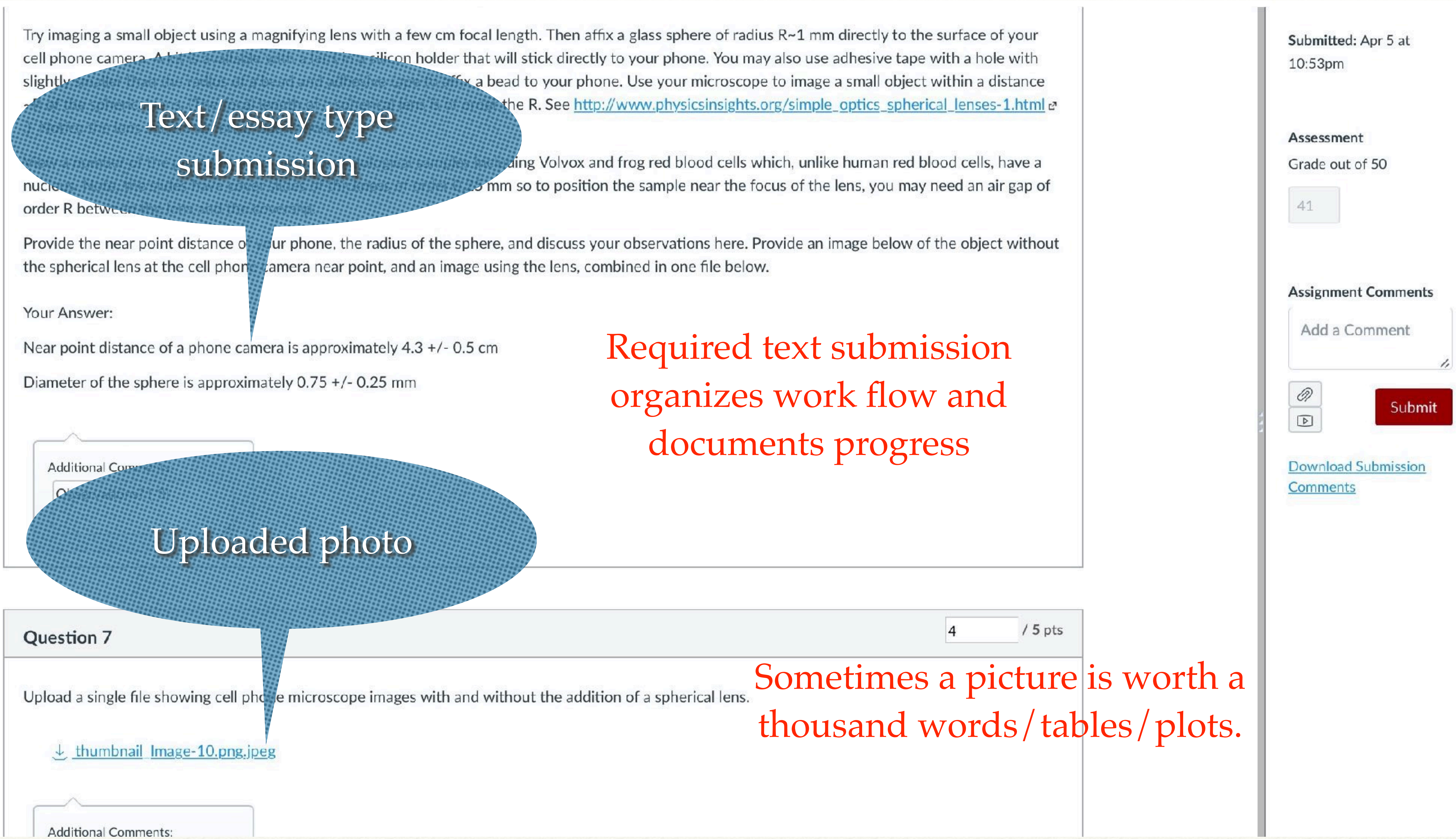
[redacted] worked in collaboration with [redacted] to gather the results discussed in this report. [redacted] collected data and observations for the digital microscope, [redacted] constructed the compound microscope and assisted [redacted] in the calculations and analysis of the compound microscope system.

REFERENCES

[1] Carlsmith, Duncan. (2019). *Physics 248 Optical Instruments Lab*.

Lab assessment in Speedgrader

- Example interactive lab procedure snippet



Outcomes:Data analysis, computation, & presentation skills

- Balmer series optical spectrometer lab

Question 4

Observation of the spectrum of hydrogen

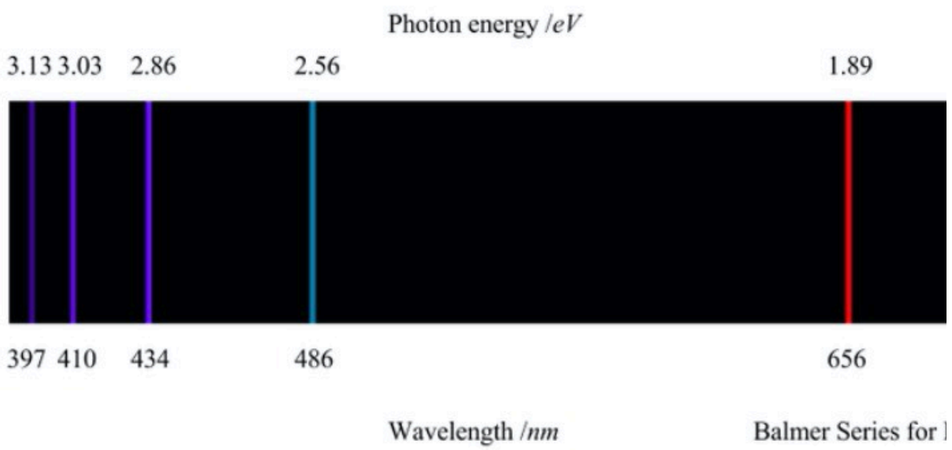
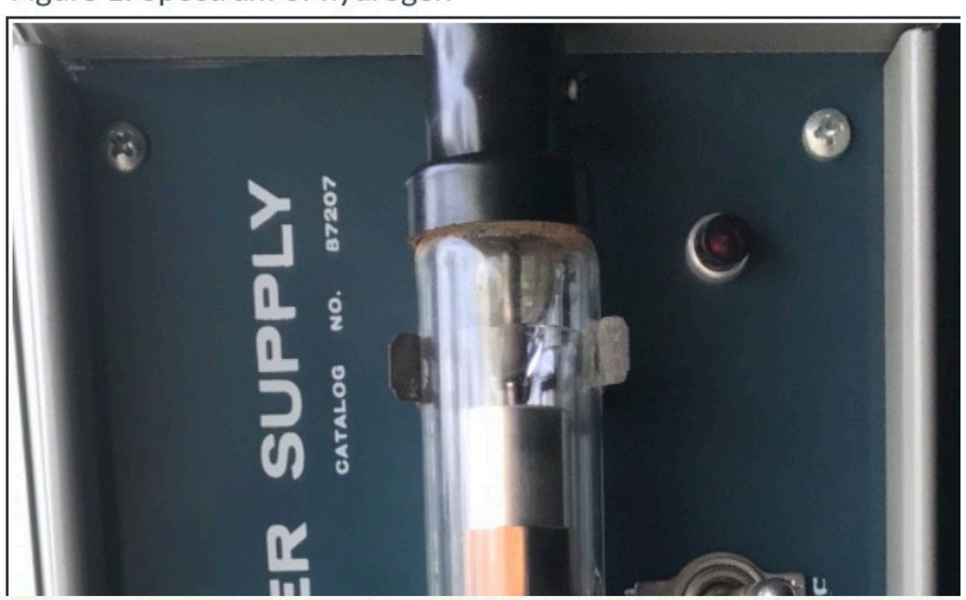


Figure 1: Spectrum of hydrogen



Hydrogen Emission Spectrum

Required pdf of executed Live Script

Here we investigate the Balmer series of hydrogen atomic emission spectra, which is produced when electrons fall from an n>=3 to the n=2 shell.For the data we obtained, 3-->2 corresponds to the red emission line, 4-->2 corresponds to the cyan line, and 5-->2 corresponds to the violet emission line.

Commented by student in LaTeX

The Balmer formula is $\frac{1}{\lambda} = R\left(\frac{1}{2^2} - \frac{1}{n^2}\right)$ where n>2 is the appropriate original energy level, R is the Rydberg constant, and lambda is the wavelength of the emitted photons.

```
Ractual = 10973731.6; %units of m^-1

n = [3, 4, 5]; %unitless
lambda = [655.9, 484.8, 433.2]*10^-9
lambdaErr = [2.3, 1.9, 2.6]*10^-9;
inverseLambda = 1./lambda;
inverseLambdaErr = (lambdaErr/lambda

figure
errorbar(n, inverseLambda, inverseLa
xlabel('n'); ylabel('1/\lambda (m^{-

%inverseLambdaExpected = Ractual*(1/

modelfun = @(R,x)R(1)*(1/4 - 1./x.^2
model = fitnlm(n, inverseLambda, mod
```

```
model =
Nonlinear regression model:
    y ~ R1*(1/4 - 1/x^2)

Estimated Coefficients:
           Estimate      SE       tStat
           ________    ______    ______

    R1    1.0993e+07   5988.1    1835.7

Number of observations: 3, Error degrees of
Root Mean Squared Error: 1.88e+03
R-Squared: 1,  Adjusted R-Squared 1
F-statistic vs. zero model: 3.37e+06, p-valu
```

```
Rfitted = model.Coefficients.Estimat
```

```
Rfitted = 1.0993e+07
```

```
RfittedError = model.Coefficients.SE
```

```
RfittedError = 5.9881e+03
```

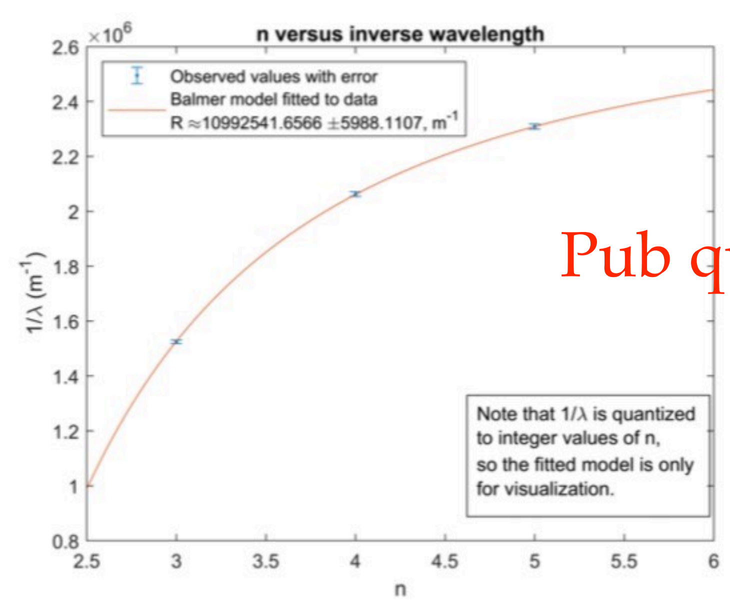
Here we can see that our fitted value for the Ry

Student code

```
hold on
nTest = linspace(2.5, 6, 100);
plot(nTest, modelfun(Rfitted, nTest))

legend('Observed values with error', strcat('Balmer model fitted to data \newline', ...
    'R \approx ', num2str(Rfitted), ' \pm ', num2str(RfittedError), ', m^{-1}'), 'Location', 'r

textboxDim = [.6 .15 .3 .2];
str = 'Note that 1/\lambda is quantized to integer values of n,\newlineso the fitted model is o
annotation('textbox', textboxDim, 'String', str)
```



Pub quality plot

This graph shows our nonlinear model fit to the data.

Nonlinear fit with standard errors=> Rydberg constant

Thanks for listening