PHYS 2CL - Electricity & Magnetism, Waves and Optics Lab

Instructor:	Leonid Butov
Office:	2117 Natural Sciences Building
E-Mail:	lvbutov@physics.ucsd.edu
Office Hours:	Mon. 2:00 PM – 3:00 PM or by appointment

Lab TA Coordinator:	Chris Palmer
Office:	2681 Mayer Hall Addition
E-Mail:	chpalmer@physics.ucsd.edu
Office Hours:	TBA

Web: http://physics.ucsd.edu/students/courses/fall2009/managed/physics2cl/

Laboratory Manual will be provided online

Textbook: J. R. Taylor, An Introduction to Error Analysis. Second Edition

Lab Notebooks: Two 7 7/8 x 10 1/8 quadrille ruled notebooks
(You will work with one notebook while the other one is being reviewed by the TA)

Final Exam (Nov 30, 7 pm, YH 2722) will cover the material in the lectures and textbook. Problems on error analysis, similar to hw problems and lecture examples.

hw problems: 10 problems from Taylor

Students should prepare for the experiment in advance by reading the lab manual. Students will be quizzed on the background by TAs in the early stage of the lab.

Quiz questions (can use notes, cannot use lab manual) Credit 2 points

Guide to the Lab Report

	Credit (10 points total)
Diagram(s) showing the overall experimental set-up and relevant electrical circuits	2
Key Equations	1
Data recording, analysis, and presentation in graphs	4
Error analysis, dominant sources of error	2
Experimental conclusions	1

Grading Policy:		
	Lab Work	6 x 12 = 72%
	Homework	10 x 1 = 10%
	Exam	18%

PHYS 2CL Fall 2009

week (starts)	lecture	exp	report due at lab section	hw due at lab section
1 (28 Sep)	Measurements and Variability. Error propagation.	0		
2 (5 Oct)	Statistical Analysis.	1	0	3.10 & 3.28
3 (12 Oct)	RC circuits (Exp. 1). Histograms and Distributions. The Gaussian Distribution.	2	1	4.18 & 4.26
4 (19 Oct)	LRC circuits (Exp. 2, 3).	3	2	
5 (26 Oct)	Refraction and Interference with Microwaves (Exp. 4).	3		5.20 & 5.36
6 (2 Nov)	Measurements Magnetic Fields (Exp. 5). Diffraction and Interference with Coherent Light (Exp. 6).	4-7 (I)	3	
7 (9 Nov)	Lenses and the Human Eye (Exp. 7).	4-7 (II)	4-7 (I)	
8 (16 Nov)	Rejection of Data, Weighted Averages, and Least Squares Fitting.	4-7 (II)	4-7 (II)	7.2 & 8.10
9 (23 Nov)	Covariance and Correlation, χ^2 Test for a Distribution.			
10 (30 Nov)	final	make-up		9.14 & 12.3

Students will do experiments 0, 1, 2, 3 during weeks 1, 2, 3, 4, 5.

In week 5, students will enlist for the remaining two experiments choosing them among experiments 4, 5, 6, 7. Students will do these two experiments during weeks 6, 7, 8.

Each experiment is performed by two students. The reports should be done individually by each student.

Lab reports will be due at the lab session one week after the experiment is performed.

Errors = Uncertainties

$$x = x_{best} \pm \delta x$$

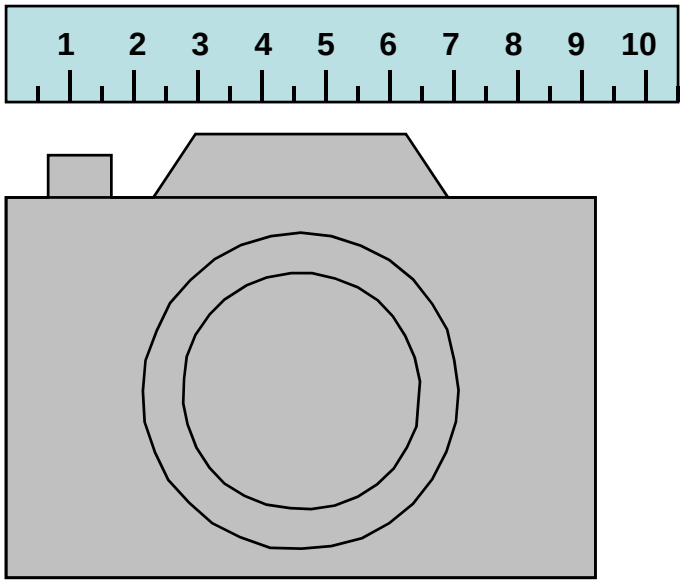
measured value of *x*

best estimate for x

uncertainty or error in the measurement

estimating uncertainties

when reading scales



$l = 9.2 \pm 0.1$ cm

in repeatable measurements

measure period of a pendulum

exp.	1	2	3	4
T, s	2.3	2.4	2.5	2.4

$T = 2.4 \pm 0.1$ s

Rounding

$$g = 9.82 \pm 0.02385 \text{ m/s}^2$$

$$g = 9.82 \pm 0.02 \text{ m/s}^2$$

Experimental uncertainties should be rounded to one significant figure (to two significant if the leading digit in the uncertainty is a 1)

$$g = 9.82 \pm 0.01437 \text{ m/s}^2$$

$$g = 9.82 \pm 0.014 \text{ m/s}^2$$

The last significant figure in any answer should be of the same order of magnitude (in the same decimal position) as the uncertainty

$$g = 9.82378 \pm 0.02 \text{ m/s}^2$$

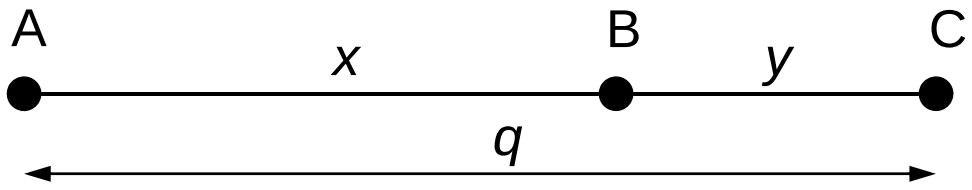
$$g = 9.82 \pm 0.02 \text{ m/s}^2$$

$g = 9.82378 \pm 0.02385 \text{ m/s}^2 \rightarrow g = 9.82378 \pm 0.02 \text{ m/s}^2 \rightarrow g = 9.82 \pm 0.02 \text{ m/s}^2$

$v = 6051.78 \pm 32 \text{ m/s} \rightarrow v = 6051.78 \pm 30 \text{ m/s} \rightarrow v = 6050 \pm 30 \text{ m/s}$

Propagation of Uncertainties

Uncertainty in a Sum



$$x = x_{best} \pm \delta x$$

$$y = y_{best} \pm \delta y$$

$$q = x + y = \left(x_{best} \pm \delta x\right) + \left(y_{best} \pm \delta y\right)$$

$$q_{\max} = \left(x_{best} + \delta x\right) + \left(y_{best} + \delta y\right) = \left(x_{best} + y_{best}\right) + \left(\delta x + \delta y\right)$$

$$q_{\min} = \left(x_{best} - \delta x\right) + \left(y_{best} - \delta y\right) = \left(x_{best} + y_{best}\right) - \left(\delta x + \delta y\right)$$

$$q = \left(x_{best} + y_{best}\right) \pm \left(\delta x + \delta y\right)$$

$$q = q_{best} \pm \delta q$$

$$q_{best} = x_{best} + y_{best}$$

$$\delta q = \delta x + \delta y$$

this equation overestimates δq because overestimate of x is accompanied by overestimate of y

$$\delta q = \sqrt{\left(\delta x\right)^2 + \left(\delta y\right)^2}$$ ← quadratic sum

correct uncertainty in a sum for independent random errors δx and δy

Uncertainties in Sums and Differences

$$x = x_{best} \pm \delta x$$

$$y = y_{best} \pm \delta y$$

$$q = x + y$$

$$q_{best} = x_{best} + y_{best}$$

$$\delta q = \sqrt{(\delta x)^2 + (\delta y)^2}$$

$$q = x - y$$

$$q_{best} = x_{best} - y_{best}$$

$$\delta q = \sqrt{(\delta x)^2 + (\delta y)^2}$$

Fractional Uncertainties

$$x = x_{best} \pm \delta x$$

$$\text{fractional uncertainty} = \frac{\delta x}{|x_{best}|}$$

Example:

$$l = 30 \pm 0.3 \text{ cm}$$

$$\frac{\delta l}{|l_{best}|} = \frac{0.3 \text{ cm}}{30 \text{ cm}} = 0.01$$

Uncertainties in Products

$$x = x_{best} \pm \delta x = x_{best}\left(1 \pm \frac{\delta x}{|x_{best}|}\right) \qquad y = y_{best} \pm \delta y = y_{best}\left(1 \pm \frac{\delta y}{|y_{best}|}\right)$$

$$q = xy = x_{best}\left(1 \pm \frac{\delta x}{|x_{best}|}\right) y_{best}\left(1 \pm \frac{\delta y}{|y_{best}|}\right)$$

$$q_{\max} = x_{best} y_{best}\left(1 + \frac{\delta x}{|x_{best}|} + \frac{\delta y}{|y_{best}|} + \frac{\delta x}{|x_{best}|}\frac{\delta y}{|y_{best}|}\right) \approx x_{best} y_{best}\left(1 + \frac{\delta x}{|x_{best}|} + \frac{\delta y}{|y_{best}|}\right)$$

$$q_{\min} \approx x_{best} y_{best}\left(1 - \frac{\delta x}{|x_{best}|} - \frac{\delta y}{|y_{best}|}\right)$$

$$q = x_{best} y_{best}\left[1 \pm \left(\frac{\delta x}{|x_{best}|} + \frac{\delta y}{|y_{best}|}\right)\right] = q_{best}\left(1 \pm \frac{\delta q}{|q_{best}|}\right)$$

$$q_{best} = x_{best} y_{best}$$

$$\frac{\delta q}{|q|} = \frac{\delta x}{|x|} + \frac{\delta y}{|y|}$$

$$\frac{\delta q}{|q|} = \sqrt{\left(\frac{\delta x}{x}\right)^2 + \left(\frac{\delta y}{y}\right)^2}$$

Example

Find momentum of a body with mass $m = 0.53 \pm 0.01$ kg moving with velosity $v = 9.1 \pm 0.3$ m/s

$$p = mv = 0.53 \times 9.1 = 4.823 \text{ kg} \cdot \text{m/s}$$

$$\frac{\delta m}{m} = \frac{0.01}{0.53} = 0.02$$

$$\frac{\delta v}{v} = \frac{0.3}{9.1} = 0.03$$

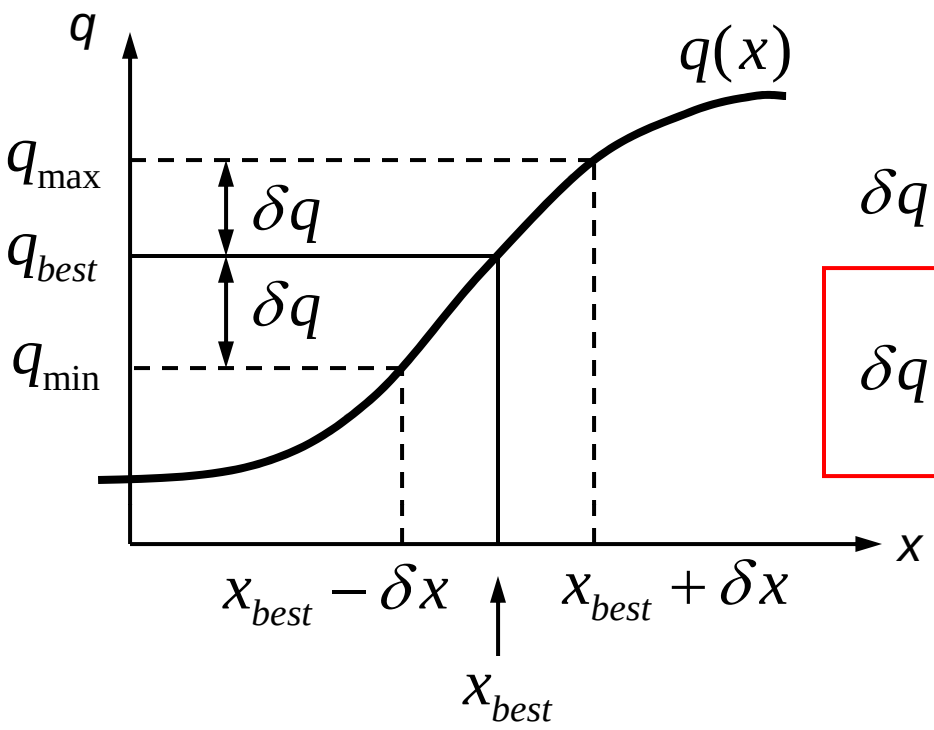
$$\frac{\delta p}{p} = \sqrt{\left(\frac{\delta m}{m}\right)^2 + \left(\frac{\delta v}{v}\right)^2} = \sqrt{0.02^2 + 0.03^2} = 0.04$$

$$\delta p = 0.04\, p = 0.04 \times 4.823 = 0.193 \text{ kg} \cdot \text{m/s}$$

$$p = 4.82 \pm 0.19 \text{ kg} \cdot \text{m/s}$$

always indicate units

Arbitrary Functions of One Variable



$$\delta q = q(x_{best} + \delta x) - q(x_{best}) = \frac{dq}{dx}\delta x$$

$$\delta q = \left|\frac{dq}{dx}\right|\delta x$$

Example

Find side *a* of a square with area $S = 25 \pm 2$ cm^2.

$$a = \sqrt{S} = \sqrt{25} = 5 \text{ cm}$$

$$\delta a = \left|\frac{da}{dS}\right|\delta S = \frac{1}{2\sqrt{S}}\delta S = \frac{1}{2\cdot\sqrt{25}}2 = 0.2 \text{ cm}$$

$$a = 5.0 \pm 0.2 \text{ cm}$$