PHYSICS 2DL – SPRING 2010

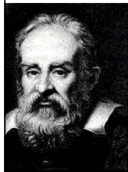
MODERN PHYSICS LABORATORY

Monday May 3, 2010

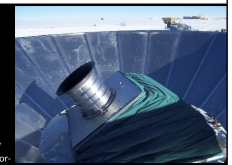
Course Week 6

Lab Week

Prof. Brian Keating



Galileo between Science, Science Studies and Science Fiction



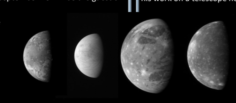
In his recent book, *Galileo's Dream*, Kim Stanley Robinson creates a portrait of Galileo's life in which he combines historic research with science fiction tropes to show the impact and challenges of paradigm shifts and their very human origins. One of the sources for this work is the research of Mario Biagioli, who will discuss the importance of Robinson's approach to historians of science and interrelationships between science studies and science fiction. Additionally, UCSD Professor of Physics Brian Keating will describe his observations of the early universe made with a version of Galileo's refractor telescope, which is sensitive to radio-waves, instead of visible light. This telescope located in Antarctica, has made ultra-sensitive images of the afterglow of the Big Bang. He will show images of the early universe as well as data from observations of Jupiter made with a new UCSD telescope, and will discuss techniques to peer deeper into the universe, standing on Galileo's shoulders. All will be framed by films of high resolution images produced by Sheldon Brown of the four Jovian moons discovered by Galileo some 400 years ago. This event is organized by Don Wayne, Provost of Revelle College.

MARIO BIAGIOLI… SHELDON BROWN… BRIAN KEATING… KIM STANLEY ROBINSON

Mario Biagioli is Professor of the History of Science at Harvard University. After studying computer science at the University of Pisa (Italy) and receiving an MFA in photography from the Visual Studies Workshop/RIT (Rochester, NY), he was awarded a PhD in history of science from UC Berkeley in 1989. His work has focused mostly on the place of science and discovery in the baroque court, and the uses of instruments, imaging techniques, and the tactical uses of print, spectacle, and display in the making of knowledge (*Galileo Courtier* (Chicago, 1993 – translated in German, Greek, Spanish, and Portuguese) and *Galileo's Instruments of Credit* (Chicago, 2006)). Along with a standing interest in the scientific revolution, he has also explored more modern topics, like Nazi science, science museums, as well as methodological debates concerning science studies and their relationship with the humanities. A Guggenheim Fellowship allowed him to develop an additional research focus on the history and philosophy of intellectual property and on the author function in science from 1600 to 'big science." He is now working on "Claiming the New" – a book on intellectual property in science. He is also the editor of *The Science Studies Reader* (Routledge, 1998), and (with Jessica Riskin) of *Nature Engaged* (Palgrave/McMillan, in press).

Sheldon Brown is the Director of the Center for Research in Computing and the Arts (CRCA) at the University of California at San Diego (UCSD) where he is a Professor of Visual Arts. He is the Site Director of the UCSD branch of the NSF sponsored Center for Hybrid Multicore Productivity Research leading its focus on next generation digital media research. He founded the New Media Arts area for the California Institute of Telecommunications and Information Technologies (Calit2), and is currently the Calit2 Artist-in-Residence. His artwork examines the relationships between mediated and physical experiences and explores the interconnections between media such as: computer gaming, virtual worlds, cinema, installation, public art and sculpture. He has shown his work at such places as The Museum of Contemporary Art in Shanghai, The Exploratorium in San Francisco, Ars Electronica in Linz Austria, The Kitchen in NYC, Zacheta Gallery in Warsaw, Centro Nacional in Mexico City, The National Academy of Science in Washington DC and others. He has been commissioned for public artworks in Seattle, San Francisco, San Diego and Mexico City, and has received grants from AT&T New Experiments in Art and Technology, the NEA, the NSF, the Rockefeller Foundation, IBM, Intel, Sun, Vicon and others.
http://sheldon-brown.net/

UCSD graduate **Kim Stanley Robinson** is a well-known science fiction writer. Author of the Mars trilogy (Red Mars, Green Mars, Blue Mars), his novels and short stories have been translated into twenty-three languages, and have been given Hugo and Nebula awards, as well as awards in England, France, Spain, and Japan. In 1995 he went to Antarctica as part of the U.S. National Science Foundation's Antarctic Artists and Writers' Program, and in 2008 he joined the Sequoia Parks Foundation's Artists In the Back Country program. Last year Time magazine named him one of their 'Heroes of the Environment.' He serves on the advisory boards of the Clarion Writer's Workshop, the Planetary Society, the Mars Association, and UCSD's Sixth College. This September he will be the guest of honor at the World Science Fiction Convention, in Melbourne, Australia.



Professor Brian Keating (PhD, Brown University 2000) is an astrophysicist with UCSD's Department of Physics and the Center for Astrophysics and Space Sciences. He guides a research team of undergraduates, graduate students, and Post-docs to develop sensitive instrumentation to study the early universe in the radio-, micro-wave- and infrared-wavelength regimes of the electromagnetic spectrum. He holds a U.S. Patent for a novel microwave polarization modulator. Keating completed postdoctoral research at Stanford University and was an NSF Postdoctoral Fellow at Caltech before coming to UCSD in 2004. In 2007 he received the Presidential Early Career Award for Scientists and Engineers at the White House from President George W. Bush for his work on a telescope he designed and fielded with his students and colleagues at the US Amundsen-Scott South Pole Research Station.

Thursday, May 6, 2010

4:30—6:00 p.m.

Calit2, Atkinson Hall

Co-Sponsored by

California Institute for Telecommunications and Information Technology (Calit2)
Clarion Writers' Workshop
Center for Research in Computing and the Arts (CRCA)
The Council of Provosts
Department of Literature
Division of Arts and Humanities
Division of Physical Sciences
Revelle College

The James K. Binder Lectureship in Literature

In commemoration of the 400th year anniversary of Galileo's telescope, the Literature Department is pleased to present...

TUESDAY, May 4, 2010

6:00 p.m.

The Atkinson Pavilion at the Faculty Club
UC San Diego

Followed by a reception

The lecture will be in English

Free and open to the public

MARIO BIAGIOLI

Inventing Invention: Galileo's Telescope Between Science and Craft

Galileo's name is routinely associated with the telescope, and vice versa. As obvious as this link may sound today, it is in fact the result of historical narratives - narratives initiated by Galileo himself. He did not invent the telescope but Galileo's telescope. His instrument, Galileo intimated, was different from all others because of the way it had been invented (through theory, not haphazard practice) and because of the unprecedented astronomical discoveries it made possible: the irregularities of the lunar surface, the satellites of Jupiter, and many more fixed stars. Galileo's claim to the inventorship of the telescope was therefore tied - necessarily so - to what he presented as the unique features of his instrument and the modalities of its invention. In the Binder Lecture, Professor Biagioli will argue that Galileo constructed his originality and that of his instruments through narratives that were themselves original, in a variety of ways.

2Day in 2DL

- Questions/Announcements
- Error Analysis: Review Ch 6 (rejecting data) Ch 7 weighted averages; NEW! Ch8 least squares fitting.
- HW due in lab this week
- Special Topic: Franck-Hertz: Using Data Acquisition to improve your life.

New Today Ch 8

- Ch 6,7 Review
- Ch 8 = Least Squares fitting

Final example

A student makes several measurements of a resistance R and determines $\bar{R}=3.5\Omega$ and $\sigma_R=0.2\ \Omega$.

Write an expression for the probability of obtaining a measured value between R_0 and $R_0+\Delta R$.

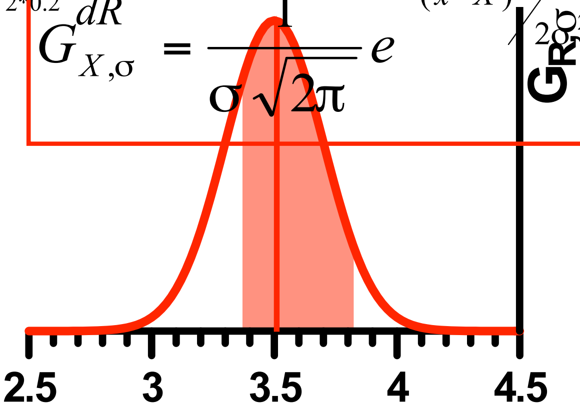
What is the probability of obtaining a measured value between 3.35Ω and 3.8Ω?

$$P = \frac{1}{0.2\sqrt{2\pi}}\int_{R_0}^{R_0+\Delta R} e^{-(R-3.5)^2/2*0.2^2}\,dR$$

$$G_{X,\sigma} = \frac{1}{\sigma\sqrt{2\pi}} e^{-(x-X)^2/2\sigma^2}$$

$$t_1 = \frac{3.5-3.35}{0.2} = 0.75$$

$$t_2 = \frac{3.8-3.5}{0.2} = 1.5$$



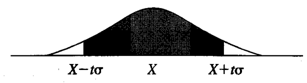
t=1.5

Then divide by 2 and add to previous

(t=0.75 sigma)

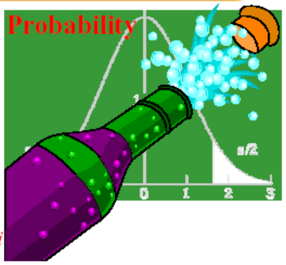
probability.

Table A. The percentage probability, $Prob(\text{within } t\sigma) = \int_{X-t\sigma}^{X+t\sigma} G_{X,\sigma}(x)\,dx$, as a function of t.



t	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.0	0.00	0.80	1.60	2.39	3.19	3.99	4.78	5.58	6.38	7.17
0.1	7.97	8.76	9.55	10.34	11.13	11.92	12.71	13.50	14.28	15.07
0.2	15.85	16.63	17.41	18.19	18.97	19.74	20.51	21.28	22.05	22.82
0.3	23.58	24.34	25.10	25.86	26.61	27.37	28.12	28.86	29.61	30.35
0.4	31.08	31.82	32.55	33.28	34.01	34.73	35.45	36.16	36.88	37.59
0.5	38.29	38.99	39.69	40.39	41.08	41.77	42.45	43.13	43.81	44.48
0.6	45.15	45.81	46.47	47.13	47.78	48.43	49.07	49.71	50.35	50.98
0.7	51.61	52.23	52.85	53.46	54.07	54.67	55.27	55.87	56.46	57.05
0.8	57.63	58.21	58.78	59.35	59.91	60.47	61.02	61.57	62.11	62.65
0.9	63.19	63.72	64.24	64.76	65.28	65.79	66.29	66.80	67.29	67.78
1.0	68.27	68.75	69.23	69.70	70.17	70.63	71.09	71.54	71.99	72.43
1.1	72.87	73.30	73.73	74.15	74.57	74.99	75.40	75.80	76.20	76.60
1.2	76.99	77.37	77.75	78.13	78.50	78.87	79.23	79.59	79.95	80.29
1.3	80.64	80.98	81.32	81.65	81.98	82.30	82.62	82.93	83.24	83.55
1.4	83.85	84.15	84.44	84.73	85.01	85.29	85.57	85.84	86.11	86.38
1.5	86.64	86.90	87.15	87.40	87.64	87.89	88.12	88.36	88.59	88.82
1.6	89.04	89.26	89.48	89.69	89.90	90.11	90.31	90.51	90.70	90.90
1.7	91.09	91.27	91.46	91.64	91.81	91.99	92.16	92.33	92.49	92.65
1.8	92.81	92.97	93.12	93.28	93.42	93.57	93.71	93.85	93.99	94.12
1.9	94.26	94.39	94.51	94.64	94.76	94.88	95.00	95.12	95.23	95.34
2.0	95.45	95.56	95.66	95.76	95.86	95.96	96.06	96.15	96.25	96.34
2.1	96.43	96.51	96.60	96.68	96.76	96.84	96.92	97.00	97.07	97.15
2.2	97.22	97.29	97.36	97.43	97.49	97.56	97.62	97.68	97.74	97.80
2.3	97.86	97.91	97.97	98.02	98.07	98.12	98.17	98.22	98.27	98.32
2.4	98.36	98.40	98.45	98.49	98.53	98.57	98.61	98.65	98.69	98.72
2.5	98.76	98.79	98.83	98.86	98.89	98.92	98.95	98.98	99.01	99.04
2.6	99.07	99.09	99.12	99.15	99.17	99.20	99.22	99.24	99.26	99.29

Averaging Data



- Random Errors can be reduced by repeated measurements.
- The best estimate of the true value of a measured quantity is the average (mean).

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$$

- We can also estimate the RMS error from the set of measurements.

$$\sigma_x^2 = \frac{1}{n-1}\sum_{i=1}^{n}\left(x_i - \bar{x}\right)^2$$

- We can then compute the error on the mean which decreases with the number of measurements.

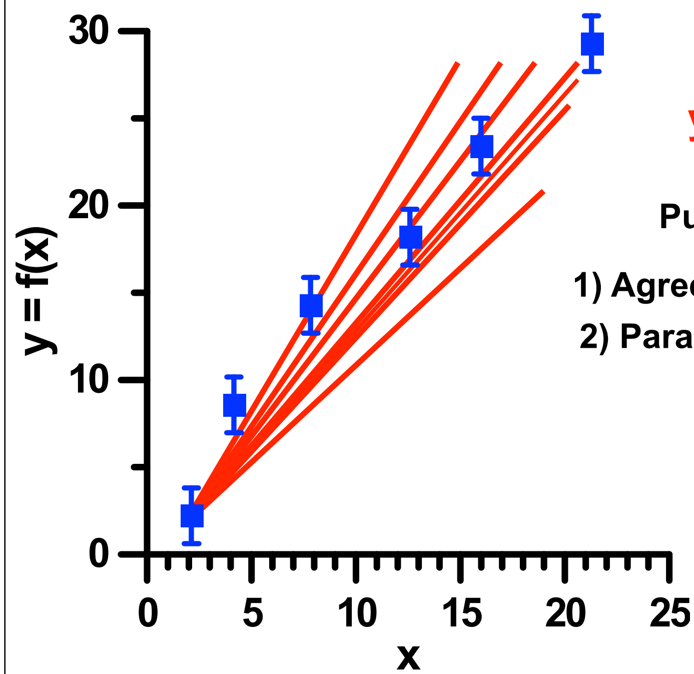
$$\sigma_{\bar{x}} = \frac{\sigma_x}{\sqrt{n}}$$

If σ_x is 1 mm, how many times must I measure to get a 0.2 mm error on the mean?

New Today Ch 8

- Ch 6,7 Review
- Ch 8 = Least Squares fitting

LEAST SQUARES FITTING (Ch.8)



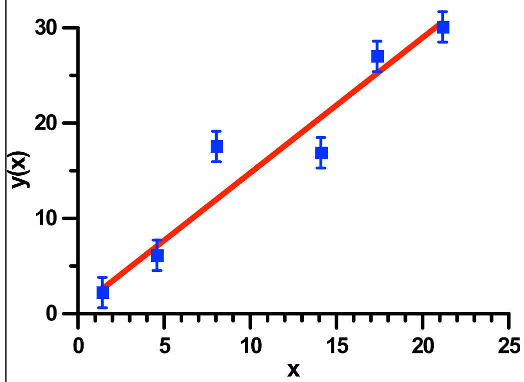
Purpose:

1) Agreement with theory?
2) Parameters

Least Sq. Fits : Derived from:

χ^2 TEST for FIT (Ch 12)

$$\chi^2 = \frac{\sum_{j=1}^{N} \left(y_j - f(x_j)\right)^2}{\sigma_y^2} \cong \frac{N\sigma_y^2}{\sigma_y^2} = N$$



$$\tilde{\chi}^2 = \frac{\chi^2}{d} \cong 1$$

d → # of degrees of freedom

LEAST SQUARES FITTING

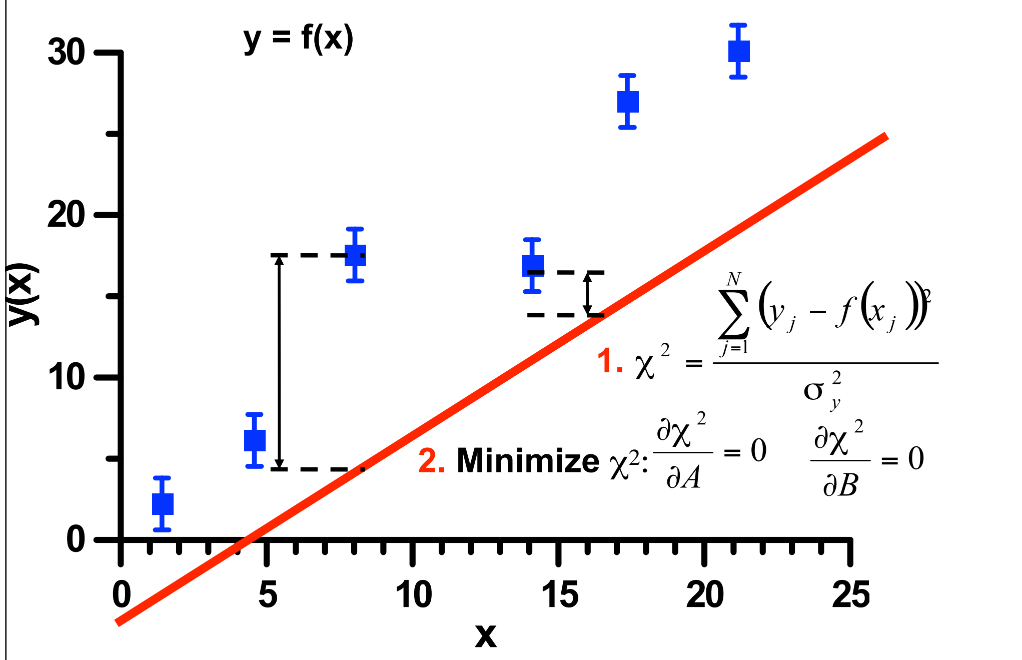
$y=A+Bx+Cx^2+Dx^3+\ldots+Zx^N$

minimize → $$\sum_{j=1}^{N}\left(y_j - f\left(x_j\right)\right)^2$$

$$\frac{\partial \sum_{j=1}^{N}\left(y_j - f\left(x_j\right)\right)^2}{\partial A} = 0 \quad \frac{\partial \sum_{j=1}^{N}\left(y_j - f\left(x_j\right)\right)^2}{\partial B} = 0 \quad \frac{\partial \sum_{j=1}^{N}\left(y_j - f\left(x_j\right)\right)^2}{\partial C} = 0 \quad \ldots$$

→ **A,B,C…**

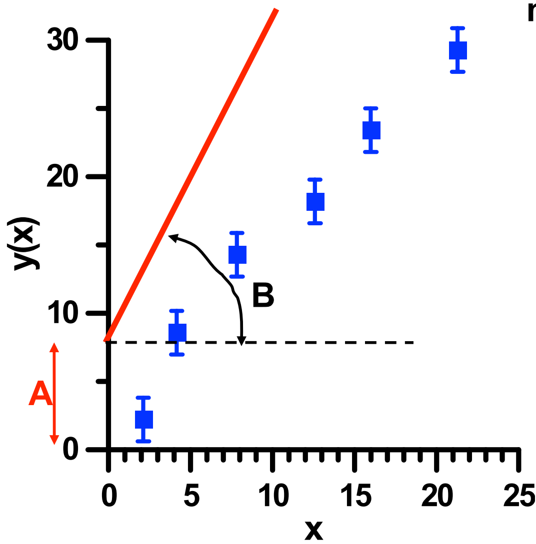
LEAST SQUARES FITTING



LINEAR FIT

$y(x) = A + Bx$:

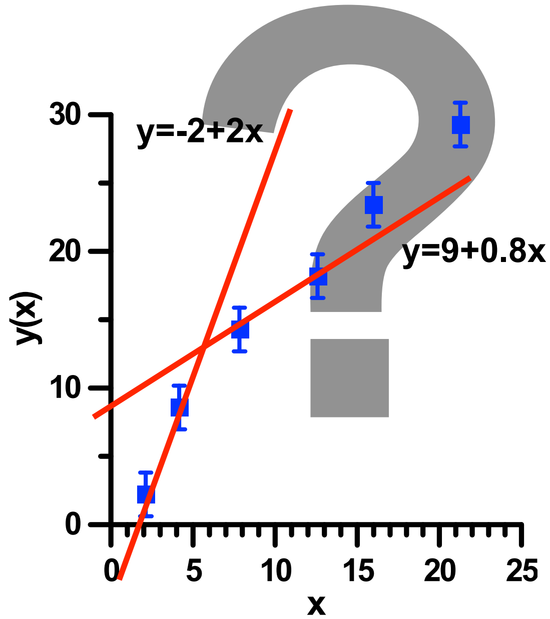
velocity at const acceleration
Ohm's law
many other…



x1	y1
x2	y2
x3	y3
x4	y4
x5	y5
x6	y6

LINEAR FIT

$y(x) = A + Bx$



x1	y1
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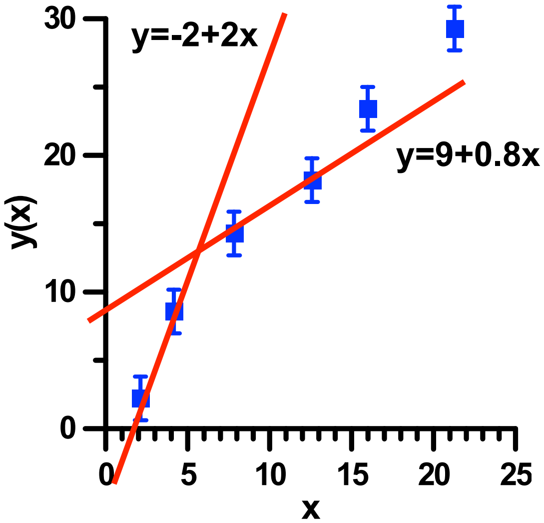
x5	y5
x6	y6

LINEAR FIT

$y(x) = A + Bx$



x1	y1
x2	y2
x3	y3
x4	y4
x5	y5
x6	y6

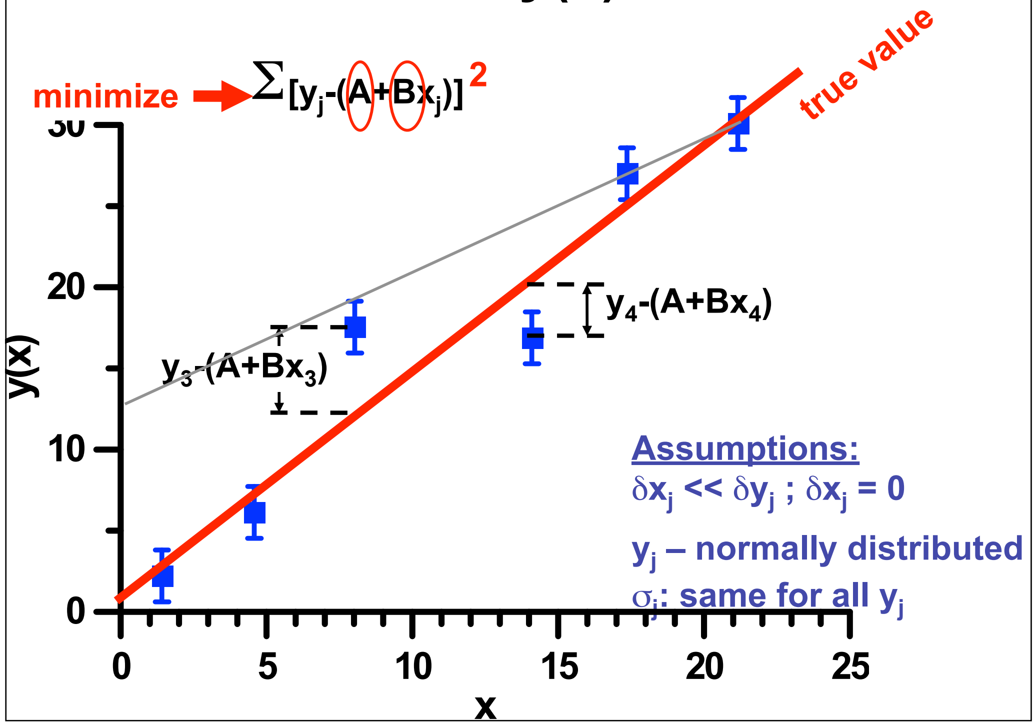
Assumptions:

1) $\delta x_j \ll \delta y_j$; $\delta x_j = 0$

2) y_j – normally distributed

3) σ_j: same for all y_j

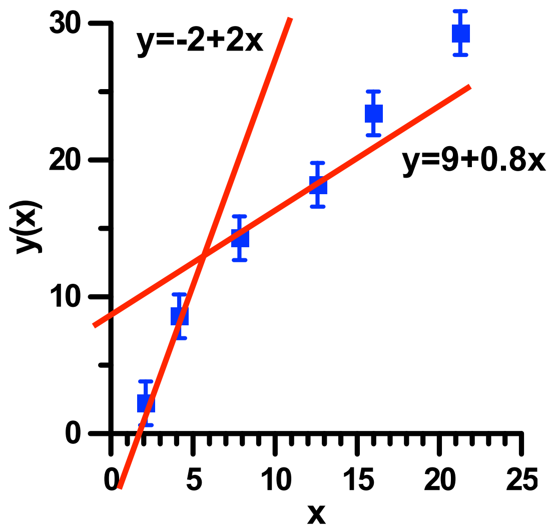
LINEAR FIT: $y(x) = A + Bx$



LINEAR FIT

y(x) = A +Bx

true value of y



x1	y1
x2	y2
x3	y3
x4	y4
x5	y5
x6	y6

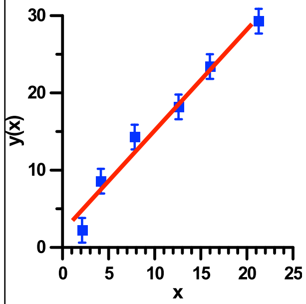
Assumptions:

1) $\delta x_j \ll \delta y_j$; $\delta x_j = 0$

2) y_j – normally distributed

3) σ_j: same for all y_j

LINEAR FIT: y(x) = A + Bx



$$\Pr ob(y_j) \propto \frac{1}{\sigma_y} \exp\left[\frac{-(y_j - y_{true})^2}{2\sigma_y^2}\right]$$

$$= \frac{1}{\sigma_y} \exp\left[\frac{-(y_j - A - Bx_j)^2}{2\sigma_y^2}\right]$$

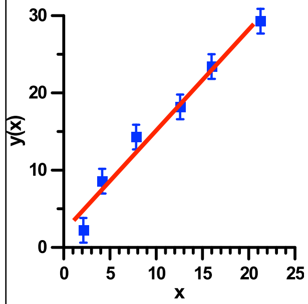
$$\Pr ob(y_1, y_2, \ldots y_N) = \Pr ob(y_1) \times \Pr ob(y_2) \times \ldots \times \Pr ob(y_N)$$

$$= \frac{1}{\sigma^N} \exp\left[\frac{-(y_1 - A - Bx_1)^2}{2\sigma_y^2} + \ldots + \frac{-(y_N - A - Bx_N)^2}{2\sigma_y^2}\right]$$

$$= \frac{1}{\sigma^N} \exp \sum_{j=1}^{N} \frac{-(y_j - A - B_j)^2}{2\sigma_y^2}$$

Best estimates of A&B → max Prob($y_1 \ldots y_N$) → min $\sum [y_j - (A + Bx_j)]^2$

LINEAR FIT: $y(x) = A + Bx$



In Taylor p. 197

$$\frac{\partial \sum \left(y_j - A - Bx_j\right)^2}{\partial A} = 0$$

$$\frac{\partial \sum \left(y_j - A - Bx_j\right)^2}{\partial B} = 0$$

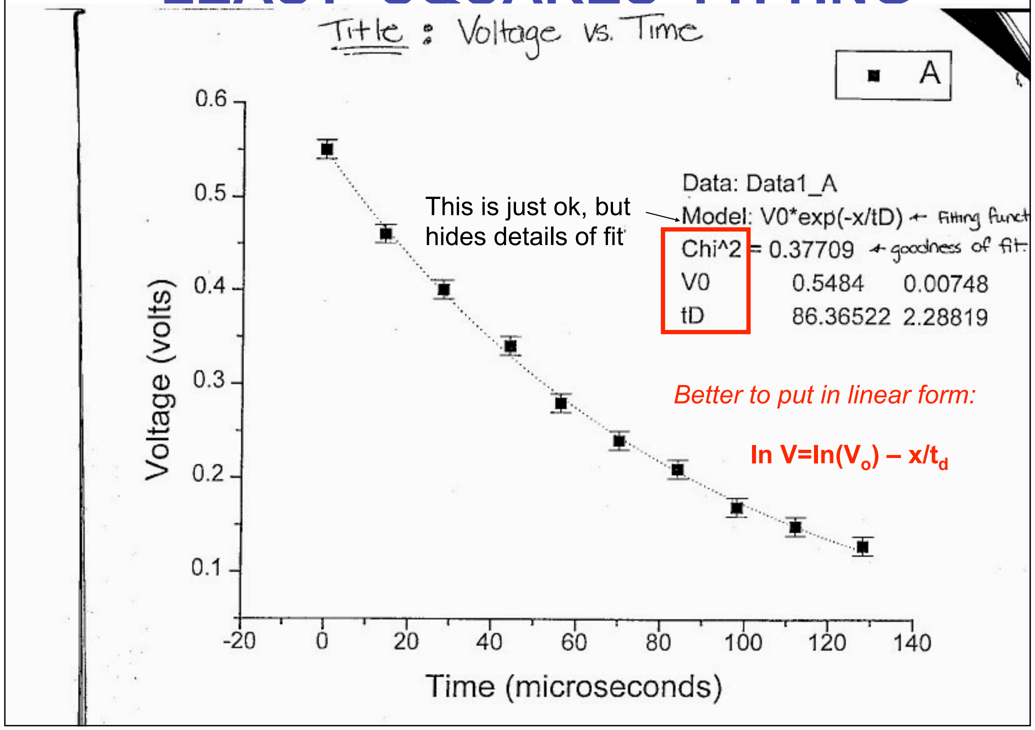
$$\Rightarrow$$

$$A = \frac{\sum x_j^2 \sum y_j - \sum x_j \sum x_j y_j}{N \sum x_j^2 - \left(\sum x_j\right)^2}$$

$$B = \frac{N \sum x_j y_j - \sum x_j \sum y_j}{N \sum x_j^2 - \left(\sum x_j\right)^2}$$

Best estimates of A&B → max Prob($y_1 \ldots y_N$) → min $\sum [y_j - (A + Bx_j)]^2$

LEAST SQUARES FITTING

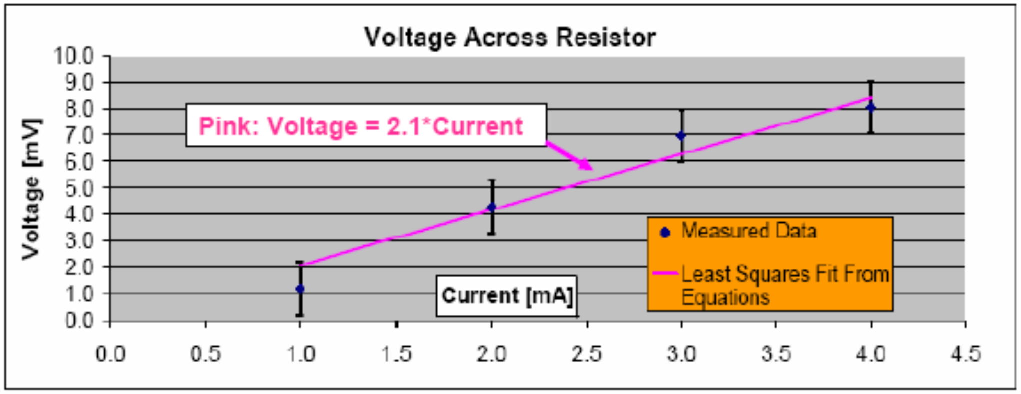


This is just ok, but hides details of fit

Better to put in linear form:

$$\ln V = \ln(V_o) - x/t_d$$

Here's our "final" example of the general technique when fitting for



Fitting Voltage Data to V=IR

$$\frac{\partial \chi^2}{\partial R} = 0$$

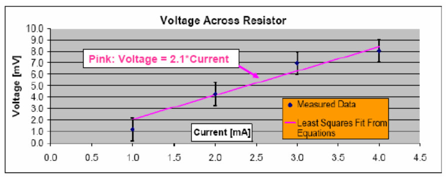
$$IMPLIES:$$

N = number of data points. In this example, N=4

$$R = \frac{\sum_{i}^{N} I_i V_i}{\sum_{i}^{N} I^2{}_i}$$

See Taylor Problem 8.18

Don't Use Linear fit with A=0!



What is the Error on the Best-Fit Parameter R?

Our general formula, which always applies, is:

$$\sigma_R = \sqrt{\left(\frac{\partial R}{\partial V_1}\right)^2 \sigma_{V_1}^2 + \left(\frac{\partial R}{\partial V_2}\right)^2 \sigma_{V_2}^2 + \ldots \left(\frac{\partial R}{\partial V_N}\right)^2 \sigma_{V_N}^2}$$

Since:

$$\left(\frac{\partial R}{\partial V_1}\right)^2 = I_1^2, \left(\frac{\partial R}{\partial V_N}\right)^2 = I_N^2$$

$$and : \sigma_{V_N} = 1mV$$

Putting it all together:

$$so : \sigma_R = \frac{1mV\sqrt{\sum_i^N I_i^2}}{\sum_i^N I_i^2}$$

Check units are right, error has same units as R.

LEAST SQUARES FITTING EXAMPLE

current [mA]	voltage [mV]	voltage error [mV]	voltage measured [mV]	voltage uncertainty [mV]	x^2 [mA^2]	xy [mA*mV]	voltage from fit [mV]
1.0	2.0	-0.8	1.2	1.0	1.0	1.2	2.1
2.0	4.0	0.3	4.3	1.0	4.0	8.6	4.2
3.0	6.0	1.0	7.0	1.0	9.0	20.9	6.3
4.0	8.0	0.0	8.0	1.0	16.0	32.1	8.4
this is "x_i"			this is "y_i"	this is "σ_Y"	$\sum x^2$ 30.0	$\sum xy$ 62.9	

This is the true signal

This is the true signal with error (uncertainty).

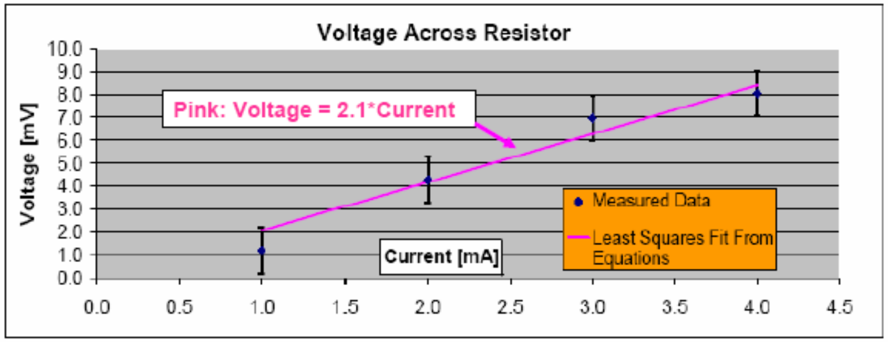
What we would measure in real-life

Our model: V=I×R

R from Fit:	$R = \sum(xy) / \sum(x^2)$	2.1 Ω

Error in R comes from partial derivative of numerator with respect to y_i only

Error in R	$\sigma_R = \sigma_Y / \sqrt{(\sum x^2)}$	0.2 Ω



LEAST SQUARES FITTING

$y=e^{Ax}$ $y=A+Bx+Cx^2+Dx^3+\ldots+Zx^N$ $y=f(x)$

minimize → $$\sum_{j=1}^{N}\left(y_j - f\left(x_j\right)\right)^2$$

$$\frac{\partial \sum_{j=1}^{N}\left(y_j - f\left(x_j\right)\right)^2}{\partial A} = 0 \quad \frac{\partial \sum_{j=1}^{N}\left(y_j - f\left(x_j\right)\right)^2}{\partial B} = 0 \quad \frac{\partial \sum_{j=1}^{N}\left(y_j - f\left(x_j\right)\right)^2}{\partial C} = 0 \quad \ldots$$

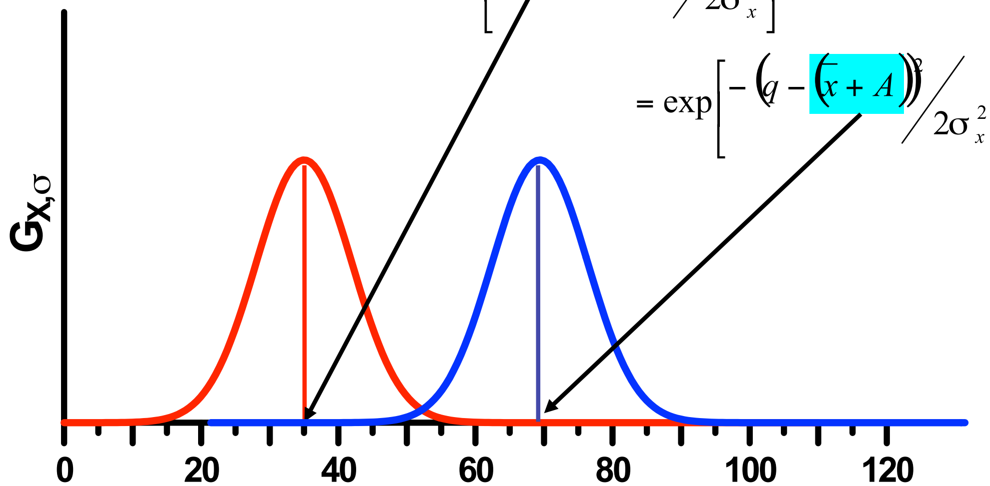
→ **A,B,C…**

q = x + A || q = Bx || q = x + y || general case

normally distributed → **prob(x)** $\propto e^{-\frac{(x-\bar{x})^2}{2\sigma_x^2}}$

prob(q)= prob(x=q-A) $\propto \exp\left[-\left((q-A)-\bar{x}\right)^2 \big/ 2\sigma_x^2\right]$

$= \exp\left[-\left(q-\left(\bar{x}+A\right)\right)^2 \big/ 2\sigma_x^2\right]$

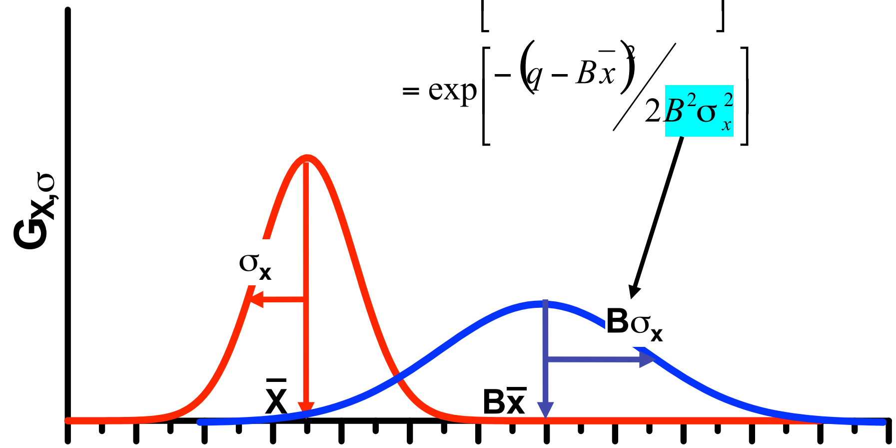


q = x + A || **q = Bx** || q = x + y || general case

prob(x) $\propto e^{-\frac{(x-\bar{x})^2}{2\sigma_x^2}}$ → **normally distributed**

prob(q) = prob(x=q/B) $\propto \exp\left[-\left(\frac{q}{B}-\bar{x}\right)^2 \Big/ 2\sigma_x^2\right]$

$$= \exp\left[-\left(q - B\bar{x}\right)^2 \Big/ 2B^2\sigma_x^2\right]$$



q = x + A || q = Bx || **q = x + y** || general case

prob(x and y) = prob(x)*prob(y)

$\bar{x}=\bar{y}=0$

$$\text{prob(x\&y)} \propto \exp\left[\frac{-x^2}{2\sigma_x^2}\right]\exp\left[\frac{-y^2}{2\sigma_y^2}\right]$$

$$= \exp\left[-\frac{1}{2}\left(\frac{x^2}{\sigma_x^2}+\frac{y^2}{\sigma_y^2}\right)\right]$$

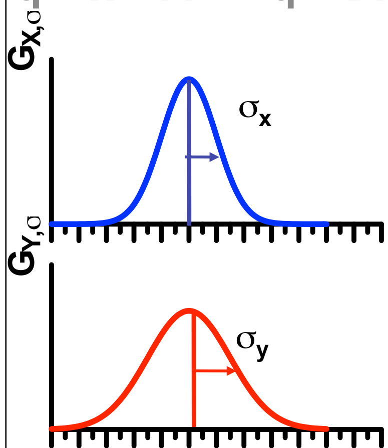
$$\text{prob(x)} \propto \exp\left[\frac{-x^2}{2\sigma_x^2}\right]$$

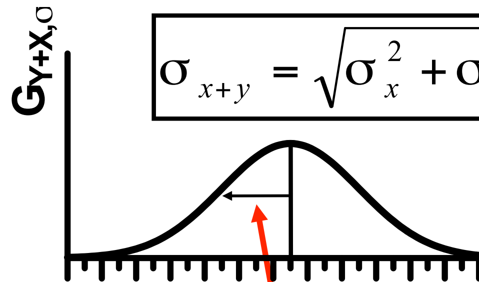
$$\text{prob(y)} \propto \exp\left[\frac{-y^2}{2\sigma_y^2}\right]$$

$$\frac{x^2}{A}+\frac{y^2}{B} = \frac{(x+y)^2}{A+B}+\frac{(Bx-Ay)^2}{AB(A+B)} = \frac{(x+y)^2}{A+B}+z^2$$

$$\text{prob(x\&y)} \propto \exp\left[-\frac{(x+y)^2}{2(\sigma_x^2+\sigma_y^2)}-\frac{z^2}{2}\right]$$

$$\text{prob(x+y and z)} \propto \exp\left[-\frac{(x+y)^2}{2(\sigma_x^2+\sigma_y^2)}\right]\exp\left[-\frac{z^2}{2}\right]$$





$$\sigma_{x+y} = \sqrt{\sigma_x^2 + \sigma_y^2}$$

prob(x+y) $= \int_{-\infty}^{\infty} prob(x+y \,\&\, z)\,dz \propto \exp\left[\frac{-(x+y)^2}{2(\sigma_x^2+\sigma_y^2)}\right] \int_{-\infty}^{\infty} e^{-\frac{z^2}{2}}\,dz$ $=(2\pi)^{0.5}$

prob(x+y and z) $\propto \exp\left[-\frac{(x+y)^2}{2(\sigma_x^2+\sigma_y^2)}\right]\exp\left[-\frac{z^2}{2}\right]$

q = x + A || q = Bx || q = x + y || **general case**

$$q(x,y) \approx q(\bar{x},\bar{y}) + \left(\frac{\partial q}{\partial x}\right)(x-\bar{x}) + \left(\frac{\partial q}{\partial y}\right)(y-\bar{y})$$

fixed number

fixed number

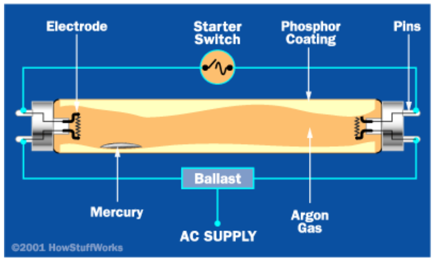
normally distributed with σ_x

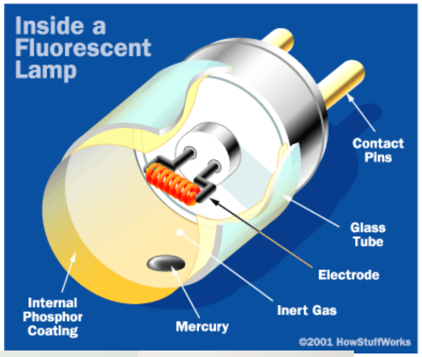
$$\frac{\partial q}{\partial x}\sigma_x \qquad \frac{\partial q}{\partial y}\sigma_y$$

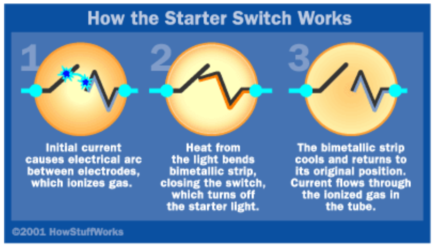
$$\sigma_q = \sqrt{\left(\frac{\partial q}{\partial x}\sigma_x\right)^2 + \left(\frac{\partial q}{\partial y}\sigma_y\right)^2}$$

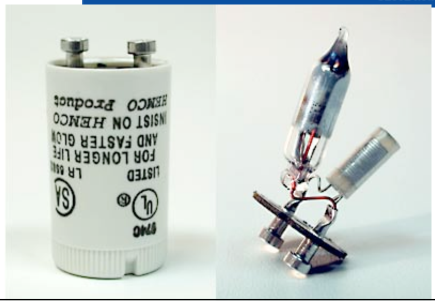
How DAQ can simplify your (experimental) life.

e$^-$-Atom collisions overhead!



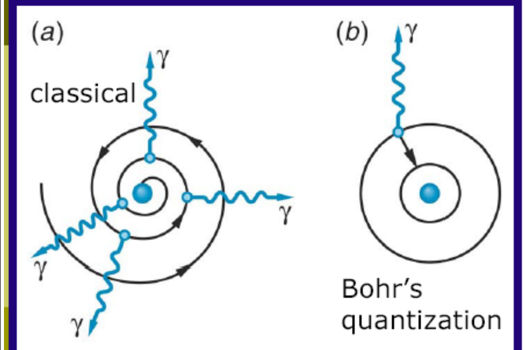


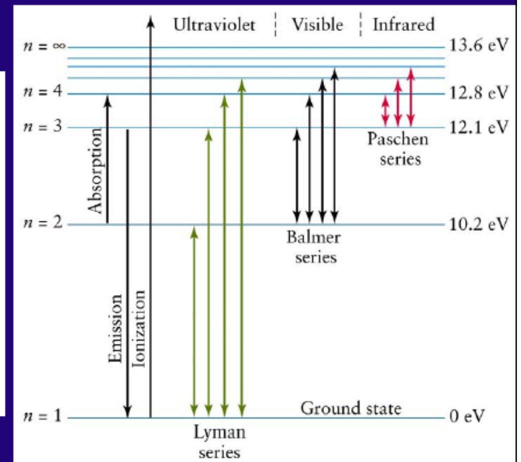




Franck-Hertz Experiment : A prelude

Bohr Atom : Discrete orbit → Emission & Absorption line



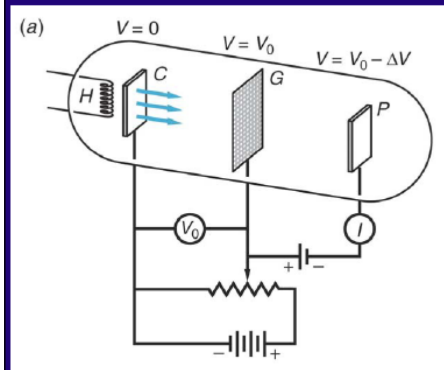


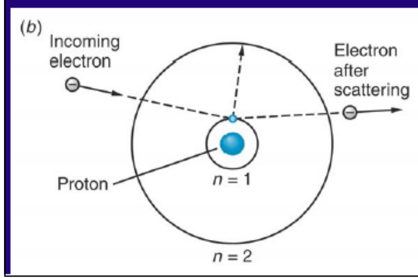
$$r_n = \frac{n^2\hbar^2}{mke^2},\ n = 1, 2, ...\infty$$

$n = 1 \Rightarrow$ Bohr Radius a_0

$$E_n = -\left(\frac{ke^2}{2a_0}\right)\frac{Z^2}{n^2}$$

Franck Hertz Experiment: Playing Football !





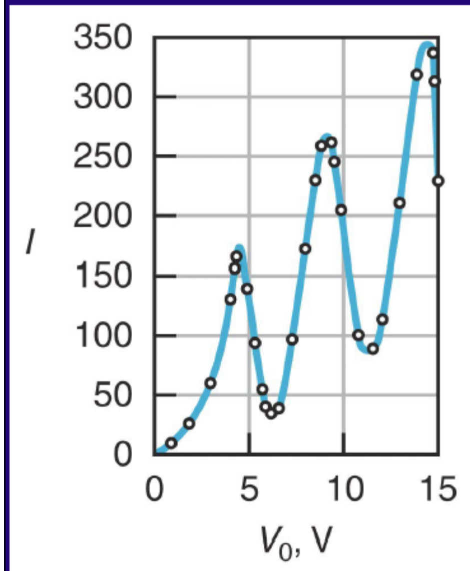
Inelastic scattering of electrons
Confirms Bohr's Energy quantization

Electrons ejected from heated cathode
At zero potential are drawn towards
the positive grid G. Those passing thru
Hole in grid can reach plate P and cause
Current in circuit if they have sufficient
Kinetic energy to overcome the retarding
Potential between G and P

Tube contains low pressure gas of stuff!

If incoming electron does not have
enough energy to transfer $\Delta E = E_2 - E_1$ then
Elastic scattering, if electron has atleast
KE= ΔE then inelastic scattering and the
electron does not make it to the plate P
→ Loss of current

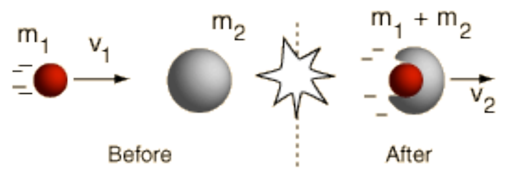
(J) Franck & (G) Hertz Experiment



Current decreases because many
Electrons lose energy due to inelasti
Scattering with the Hg atom in tube
And therefore can not overcome the
Small retarding potential between
G → P

The regular spacing of the peaks
Indicates that ONLY a certain quanti
Of energy can be lost to the Hg ato
ΔE=4.9 eV.

This interpretation can be confirmed
Observation of radiation of photon e
E=hf=4.9 eV emitted by Hg atom wl
V_0 > 4.9V



	Before	After
Momentum	$m_1 v_1$	$(m_1 + m_2)v_2$
Kinetic energy	$\frac{1}{2} m_1 v_1^2$	$\frac{1}{2}(m_1 + m_2)v_2^2$

From conservation of momentum:

$$m_1 v_1 = (m_1 + m_2)v_2 \Rightarrow v_2 = \frac{m_1}{m_1 + m_2} v_1$$

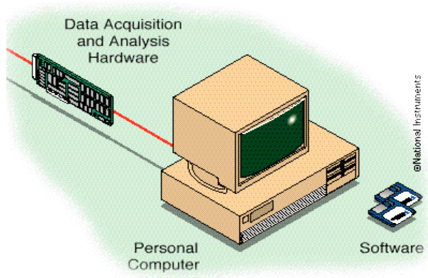
Ratio of kinetic energies before and after collision:

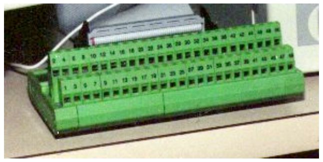
$$\frac{KE_f}{KE_i} = \frac{m_1}{m_1 + m_2}$$

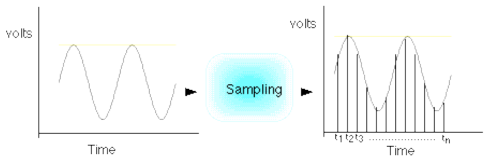
Fraction of kinetic energy lost in the collision:

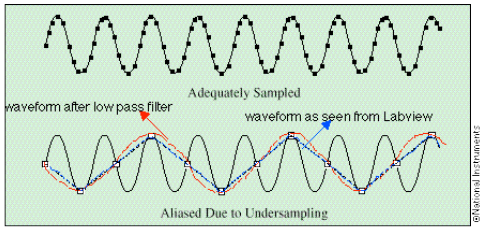
$$\frac{KE_i - KE_f}{KE_i} = \frac{m_2}{m_1 + m_2}$$

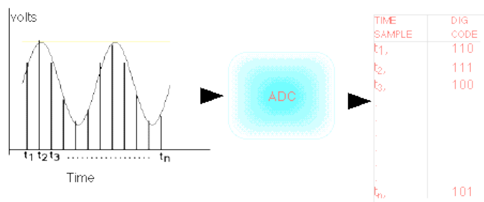
Electronic Measurement using Digital to Analog Conversion

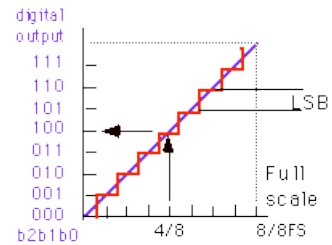


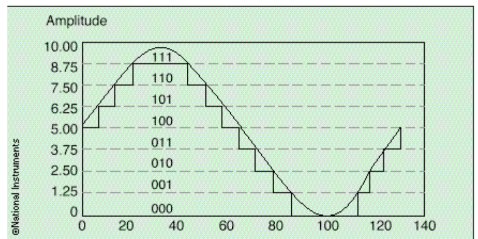


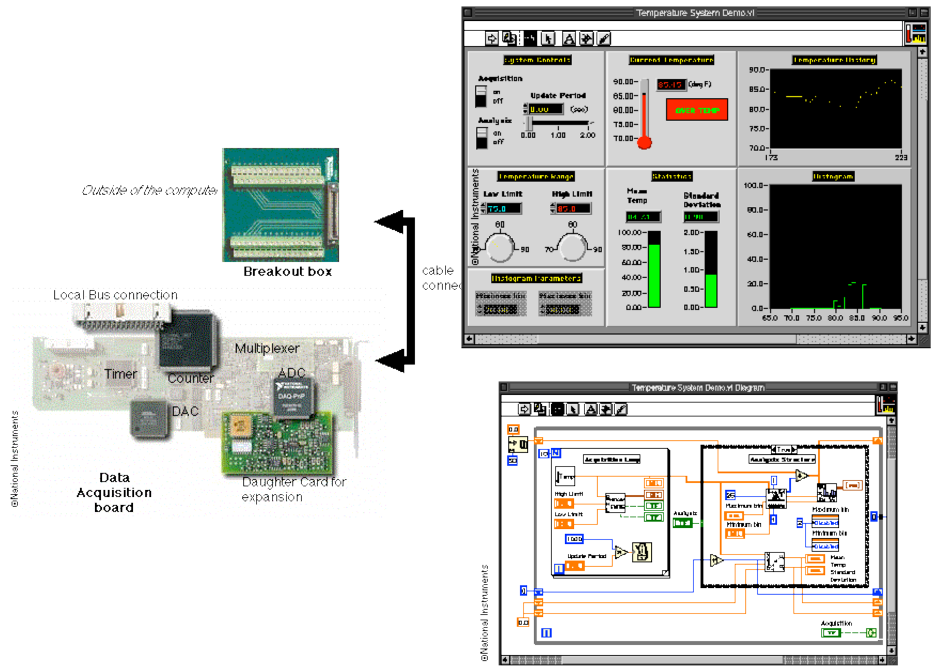





volts
Time
ADC
TIME SAMPLE
DIG CODE
t1. 110
t2. 111
t3. 100
tn. 101


digital output
111
110
101
100
011
010
001
000
b2b1b0
LSB
Full scale
4/8
8/8FS


Amplitude
10.00
8.75
7.50
6.25
5.00
3.75
2.50
1.25
0
111
110
101
100
011
010
001
000
0
20
40
60
80
100
120
140
©National Instruments


Outside of the compute
Breakout box
cable
Local Bus connection
Multiplexer
Timer
Counter
ADC
DAC
Data Acquisition board
Daughter Card for expansion
©National Instruments
Temperature System Demo.vi
Temperature System Demo.vi Diagram
©National Instruments

Franck Hertz DAQ

- Program (called a ".vi" file) is on Floppy drive.
- Save data to hard disk, on desktop.
- Email yourself the data from IE
- Save channel 1 data (acceleration voltage)
- Channel 2 is current, measured as a voltage