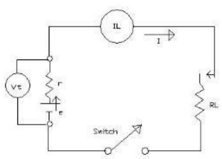
Introduction:

In this lab, we are testing a popular model of a real battery by checking our experimental data to see if it fits predictions made by analysing the model. We have predicted two formulas by applying conservation of energy techniques to the model. This model of a real battery, which consists of an internal resistance and an ideal battery, predicts the formulas $\Delta(V) = -r\,I + \varepsilon$ and $P_L = R\,I^2 \quad \_ = R\left(\frac{\varepsilon}{r+R}\right)^2$. In plotting the potential difference versus the current while using a variable resistor, our model predicts that ε will be the y-intercept and the slope of the graph multiplied by negative one will be the internal resistance. Now, if we compare the data taken from two different configurations of battery with equivalent terminal voltages (one 9volt battery and 6 1.5volt batteries) we should observe a significant difference in intercept and slope for each of the two configurations. We will confirm our results by comparing these results to similar alternate results taken by calculating the internal resistance from the power gained by the load resistor in each configuration. We have predicted load resistor in the 6 1.5volt batteries will gain less power because more will be absorbed by the greater internal resistance.

Procedures: Full procedures available in the 1999-2000 edition of the physics NYB lab manual experiment # 2 or upon request at j_con999@@yahoo.com

Diagram:

Diagram 1



Data: Experimental Data available upon request. Contact me at j_con999@yahoo.com

Calculations:

Part 1 1 9-Volt battery

for i from 1 to 3 do

```
readline("a:/Lab4/1_9V/Run1.txt")
od;
```

"Ch A\tCh B"

"Run #3\tRun #3"

"Voltage (V)\tCurrent (A)"

```
R1:=readdata("a:/Lab4/1_9V/Run1.txt",2):nops(%);
```

30

```
Voltage1:=[seq(R1[i,1],i=1..30)]:
Intensity1:=[seq((R1[i,2]),i=1..30)]:
Data1:=[seq([Intensity1[i],Voltage1[i]],i=1..30)]:
A:=plot(Data1,style=point,symbol=circle):
Eq:=fit[leastsquare[[x,y],y=a*x+b,{a,b}]]([Intensity1[5..25],Voltage1[5..25]]);
```

$$Eq := y = -5.923\,x + 8.361$$

```
FR1:=unapply(rhs(%),x);
```

$$FR1 := x \to -5.923\,x + 8.361$$

```
B:=plot(FR1(x),x=(-.1)..1.5):
C:=textplot([0.5,7.5,`Middle=Best Line`],colour=red,align=ABOVE):
G:=textplot([1.2,2.5,`Max Line`],colour=green,align=ABOVE):
H:=textplot([0.2,4,`Min Line`],colour=blue,align=ABOVE):
J:=[.16,.79]:K:=[7.28,3.88]:L:=[1.06,.16]:
M:=[1.69,7.70]:
EqMax:=fit[leastsquare[[x,y],y=a*x+b,{a,b}]]([J,K]);
```

$$EqMax := y = -5.402\,x + 8.146$$

Fmax:=unapply(rhs(%),x);

$$Fmax := x \rightarrow -5.402\,x + 8.146$$

PMax:=plot(Fmax(x),x=-.1..1.5):

EqMin:=fit[leastsquare[[x,y],y=a*x+b,{a,b}]]([L,M]);

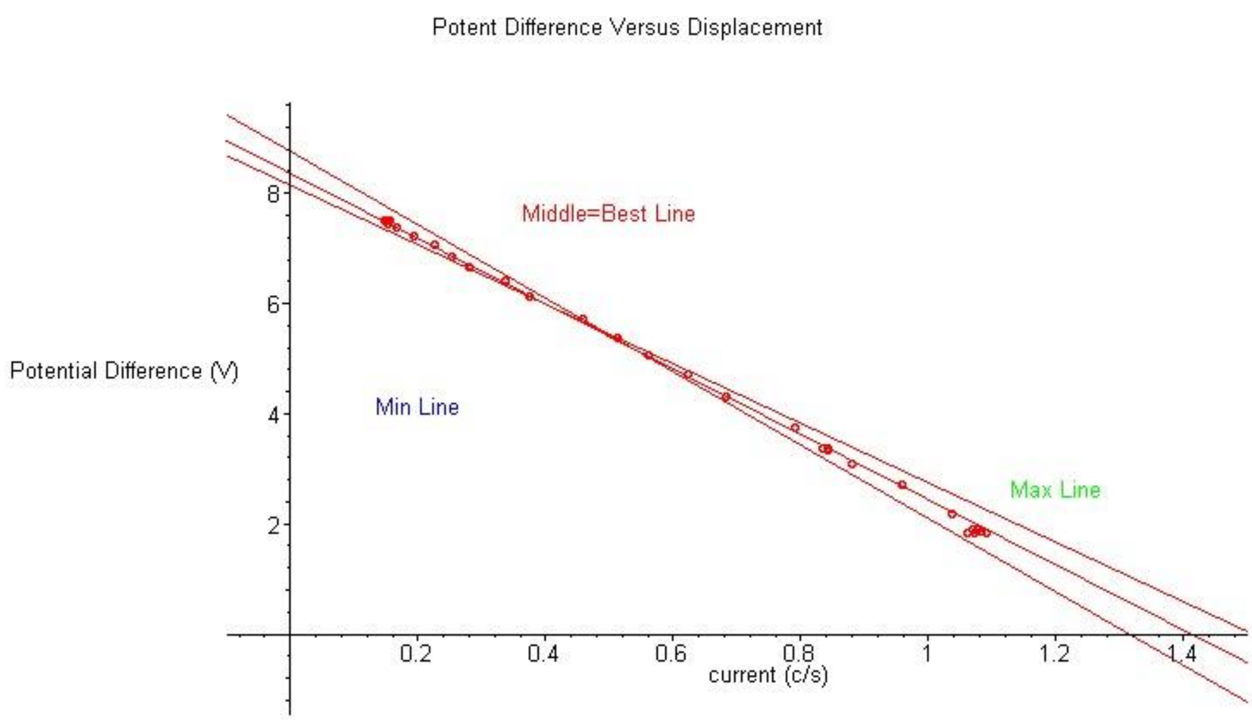
$$EqMin := y = -6.666\,x + 8.761$$

Fmin:=unapply(rhs(%),x);

$$Fmin := x \rightarrow -6.666\,x + 8.761$$

PMin:=plot(Fmin(x),x=-.1..1.5):

display([A,B,C,G,H,PMax,PMin],title="Potent Difference Versus Displacement",labels=["current (c/s)","Potential Difference (V)"]);



`data slope 1`:=-5.923;

```
`min slope 1`:=-6.666; `max slope 1`:=-5.402;

uncertainty1:=abs((`max slope 1`-`min slope 1`)/2);

`% uncertainty 1`:=abs(uncertainty1/`data slope 1`*100);
```

$$data\ slope\ 1 := -5.923$$

$$min\ slope\ 1 := -6.666$$

$$max\ slope\ 1 := -5.402$$

$$uncertainty1 := .632$$

$$\%\ uncertainty\ 1 := 10.67$$

```
`Data intersept`:=8.361;

`min intersept`:=8.146; `max intersept`:=8.761;

uncertaintyi1:=abs((`max intersept`-`min intersept`)/2);

`% uncertaintyi 1`:=abs(uncertaintyi1/`Data intersept`*100);
```

$$Data\ intersept := 8.361$$

$$min\ intersept := 8.146$$

$$max\ intersept := 8.761$$

$$uncertaintyi1 := .308$$

$$\%\ uncertaintyi\ 1 := 3.684$$

Part 2

6 1.5-Volt

batteries **for i from 1**

to 3 do

readline("a:/Lab4/6_1_5V/Run3.txt")

```
od;
```

"Ch A\tCh B"

"Run #1\tRun #1"

"Voltage (V)\tCurrent (A)"

```
R2:=readdata("a:/Lab4/6_1_5V/Run3.txt",2):nops(%);
```

219

```
Voltage2:=[seq(R2[i,1],i=1..219)]:

Intensity2:=[seq((R2[i,2]),i=1..219)]:

Data2:=[seq([Intensity2[i],Voltage2[i]],i=1..219)]:

A:=plot(Data2,style=point,symbol=circle):

Eq:=fit[leastsquare[[x,y],y=a*x+b,{a,b}]]([Intensity2,Voltage2]);
```

$$Eq := y = -9.031\, x + 9.149$$

```
FR2:=unapply(rhs(%),x);
```

$$FR2 := x \to -9.031\, x + 9.149$$

```
B:=plot(FR2(x),x=(-.1)..1.2):

C:=textplot([0.5,7.5,`Middle=Best Line`],colour=red,align=ABOVE):

G:=textplot([1,2,`Max Line`],colour=green,align=ABOVE):

H:=textplot([.4,4,`Min Line`],colour=blue,align=ABOVE):

J:=[.8,.4]:K:=[2.31,5.42]:L:=[.82,.18]:M:=[1.46,7.76]:

Eqmax2:=fit[leastsquare[[x,y],y=a*x+b,{a,b}]]([J,K]);
```

$$Eqmax2 := y = -7.775\, x + 8.530$$

```
Fmax2:=unapply(rhs(%),x);
```

$$Fmax2 := x \to -7.775\, x + 8.530$$

PMax2:=plot(Fmax2(x),x=-.1..1.2):

Eqmin2:=fit[leastsquare[[x,y],y=a*x+b,{a,b}]]([L,M]);

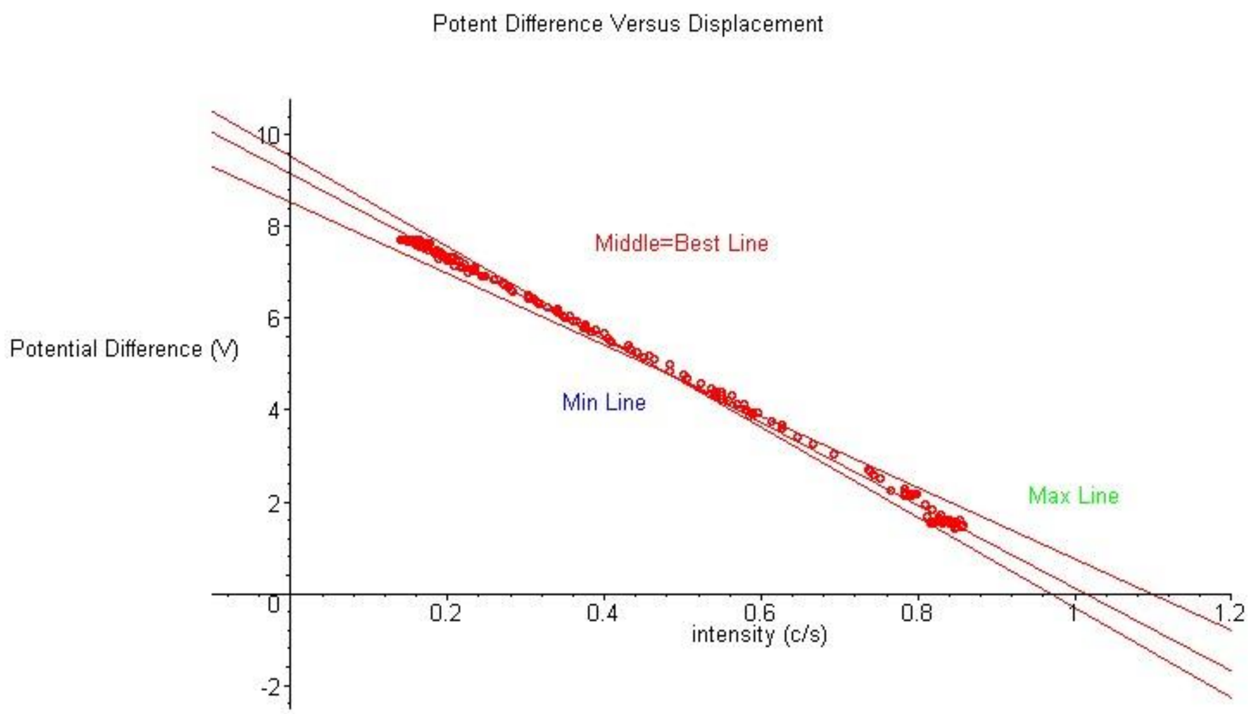
$$Eqmin2 := y = -9.834\,x + 9.527$$

Fmin2:=unapply(rhs(%),x);

$$Fmin2 := x \to -9.834\,x + 9.527$$

PMin2:=plot(Fmin2(x),x=-.1..1.2):

display([A,B,C,G,H,PMax2,PMin2],title="Potent Difference Versus Displacement",labels=["intensity (c/s)","Potential Difference (V)"]);



`data slope 2`:=-9.031;

`min slope 2`:=-9.834; `max slope 2`:=-7.775;

uncertainty2:=abs((`max slope 2`-`min slope 2`)/2);

`% uncertainty 2`:=abs(uncertainty2/`data slope 2`*100);

$$data\ slope\ 2 := -9.031$$

$$min\ slope\ 2 := -9.834$$

$$max\ slope\ 2 := -7.775$$

$$uncertainty2 := 1.029$$

$$\%\ uncertainty\ 2 := 11.39$$

`Data intersept 2`:=9.149;

`min intersept 2`:=8.530; `max intersept 2`:=9.527;

uncertaintyi2:=abs((`max intersept 2`-`min intersept 2`)/2);

`% uncertaintyi 2`:=abs(uncertaintyi2/`Data intersept 2`*100);

$$Data\ intersept\ 2 := 9.149$$

$$min\ intersept\ 2 := 8.530$$

$$max\ intersept\ 2 := 9.527$$

$$uncertaintyi2 := .499$$

$$\%\ uncertaintyi\ 2 := 5.454$$

Power Calculations :

Part 1

R[load1]:=[seq(Voltage1[i]/Intensity1[i],i=1..30)]:

P:=[seq(Voltage1[i]*Intensity1[i],i=1..30)]:

Data[power]:=[seq([R[load1][i],P[i]],i=1..30)]:

A:=plot(Data[power],x=0..60,style=point,symbol=circle): eqP1:=y=(`Data intersept`/(x-`data slope 1`))^2*x;

$$eqP1 := y = 69.91 \frac{x}{(x+5.923)^2}$$

FP1:=unapply(rhs(%),x);

$$FP1 := x \to 69.91 \frac{x}{(x+5.923)^2}$$

B:=plot(FP1(x),x=0..60): d1:=diff(rhs(eqP1),x);

`Maximum Power Lost in the battery`:=fsolve(d1=0,x);

$$d1 := -139.8 \frac{x}{(x+5.923)^3} + 69.91 \frac{1}{(x+5.923)^2}$$

$$\text{Maximum Power Lost in the battery} := 5.925$$

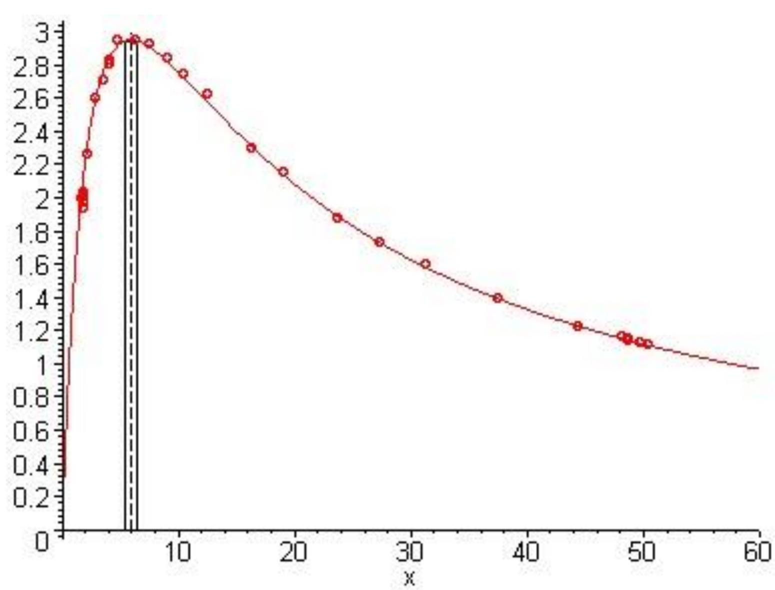
lmax:=line([`Maximum Power Lost in the battery`+.5,FP1((`Maximum Power Lost in the battery`+.5))], [`Maximum Power Lost in the battery`+.5,0]):

lmin:=line([`Maximum Power Lost in the battery`-.5,FP1((`Maximum Power Lost in the battery`-.5))], [`Maximum Power Lost in the battery`-.5,0]):

lcon:=line([`Maximum Power Lost in the battery`+.5,FP1((`Maximum Power Lost in the battery`+.5))], [`Maximum Power Lost in the battery`.5,FP1(`Maximum Power Lost in the battery`-.5)]):

l1:=line([`Maximum Power Lost in the battery`,0], [`Maximum Power Lost in the battery`,3],linestyle=3):

display([A,B,lmax,lmin,lcon,l1]);



`internal resistance Uncertainty1`:=((`Maximum Power Lost in the battery`+.5)-(`Maximum Power Lost in the battery`-.5))/2;

$$internal\ resistance\ Uncertainty1 := .5000$$

`internal resistance % Uncertainty1`:=`internal resistance Uncertainty1`/`Maximum Power Lost in the battery`*100;

$$internal\ resistance\ \%\ Uncertainty1 := 8.439$$

Part 2

R[load2]:=[seq(Voltage2[i]/Intensity2[i],i=1..219)]:

P2:=[seq(Voltage2[i]*Intensity2[i],i=1..219)]:

Data[power2]:=[seq([R[load2][i],P2[i]],i=1..219)]:

A:=plot(Data[power2],x=0..60,style=point,symbol=circle): eqP2:=y=(`Data

intersept 2`/(x-`data slope 2`))^2*x;

$$eqP2 := y = 83.70 \frac{x}{(x+9.031)^2}$$

FP2:=unapply(rhs(%),x);

$$FP2 := x \rightarrow 83.70 \frac{x}{(x+9.031)^2}$$

B:=plot(FP2(x),x=0..60): d2:=diff(rhs(eqP2),x);

`Maximum Power Lost in the battery2`:=fsolve(d2=0,x);

$$d2 := -167.4 \frac{x}{(x+9.031)^3} + 83.70 \frac{1}{(x+9.031)^2}$$

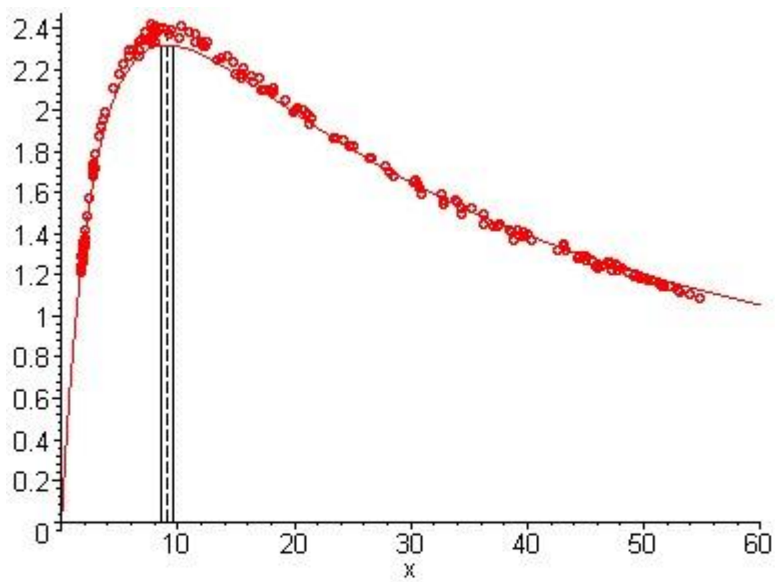
$$Maximum\ Power\ Lost\ in\ the\ battery2 := 9.031$$

lmax:=line([`Maximum Power Lost in the battery2`+.5,FP2((`Maximum Power Lost in the battery2`+.5))], [`Maximum Power Lost in the battery2`+.5,0]):

lmin:=line([`Maximum Power Lost in the battery2`-.5,FP2((`Maximum Power Lost in the battery2`-.5))], [`Maximum Power Lost in the battery2`-.5,0]):

lcon:=line([`Maximum Power Lost in the battery2`+.5,FP2((`Maximum Power Lost in the battery2`+.5))], [`Maximum Power Lost in the battery2`.5,FP2(`Maximum Power Lost in the battery2`-.5)]):

l2:=line([`Maximum Power Lost in the battery2`,0], [`Maximum Power Lost in the battery2`,2.4],linestyle=3): display([A,B,lmax,lmin,lcon,l2]);



`internal resistance Uncertainty2`:=((`Maximum Power Lost in the battery2`+.5)-(`Maximum Power Lost in the battery2`-.5))/2;

> **`internal resistance % Uncertainty2`:=`internal resistance Uncertainty2`/`Maximum Power Lost in the battery2`*100;**

internal resistance Uncertainty2 := .5000

internal resistance % Uncertainty2 := 5.536

Percentage of Difference Calculations

Part 1

`% Difference of Part 1`:=abs(((-1)*`data slope 1`-`Maximum Power Lost in the battery`)/((-1)*`data slope 1`+`Maximum Power Lost in the battery`)*200);

$$\%\ Difference\ of\ Part\ 1 := .03376$$

Part 2

`% Difference of Part 2`:=abs(((-1)*`data slope 2`-`Maximum Power Lost in the battery2`)/((-1)*`data slope 2`+`Maximum Power Lost in the battery2`)*200);

$$\%\ Difference\ of\ Part\ 2 := 0$$

Experimental Results :

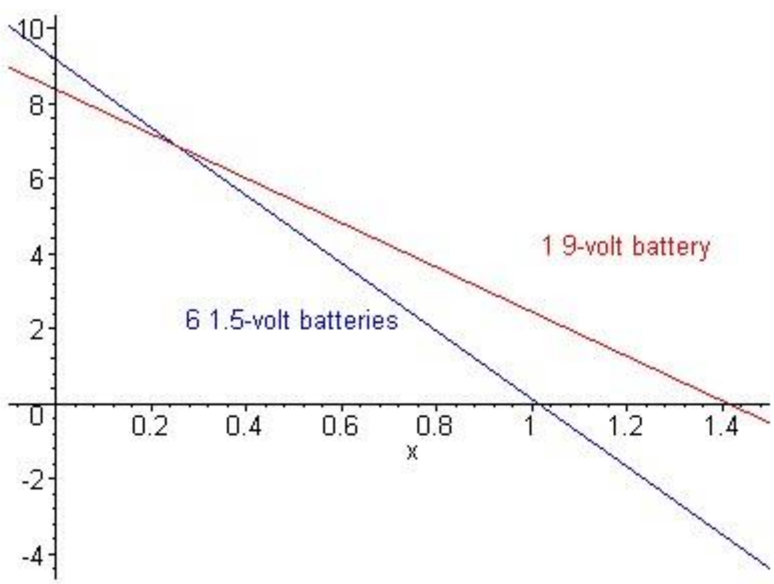
A:=plot(FR1(x),x=(-.1)..1.5):

B:=plot(FR2(x),x=(-.1)..1.5,color=blue):

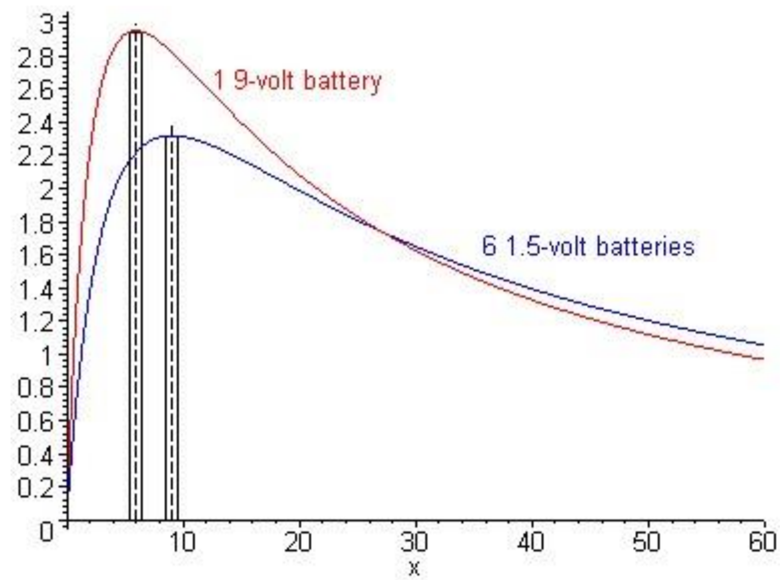
C:=textplot([1.2,4,`1 9-volt battery`],colour=red,align=ABOVE):

E:=textplot([.5,2,`6 1.5-volt batteries`],colour=blue,align=ABOVE):

display([A,B,C,E]);

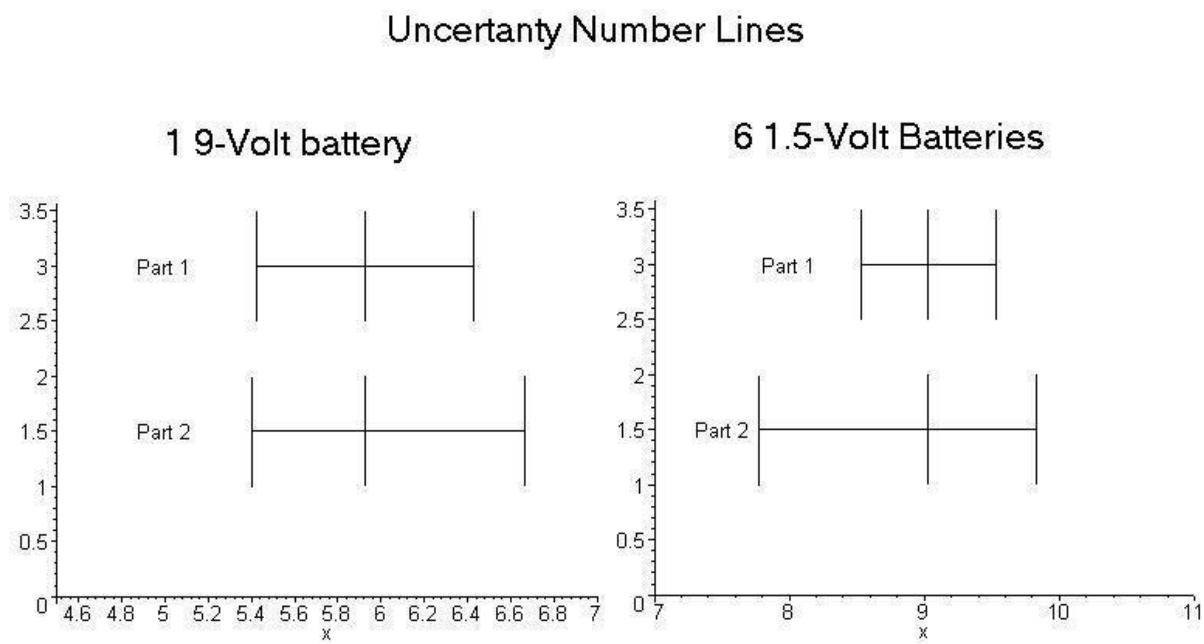


```
F:=plot(FP1(x),x=0..60):

G:=plot(FP2(x),x=0..60,color=blue):

H:=textplot([20,2.6,`1 9-volt battery`],colour=red,align=ABOVE):

J:=textplot([45,1.6,`6 1.5-volt batteries`],colour=blue,align=ABOVE):

lmax:=line([`Maximum Power Lost in the battery`+.5,FP1((`Maximum Power Lost in the battery`+.5))], [`Maximum Power Lost in the battery`+.5,0]):

lmin:=line([`Maximum Power Lost in the battery`-.5,FP1((`Maximum Power Lost in the battery`-.5))], [`Maximum Power Lost in the battery`-.5,0]):
lcon:=line([`Maximum Power Lost in the battery`+.5,FP1((`Maximum Power Lost in the battery`+.5))], [`Maximum Power Lost in the battery`.5,FP1(`Maximum Power Lost in the battery`-.5)]):

l1:=line([`Maximum Power Lost in the battery`,0], [`Maximum Power Lost in the battery`,3],linestyle=3):

lmax2:=line([`Maximum Power Lost in the battery2`+.5,FP2((`Maximum Power Lost in the battery2`+.5))], [`Maximum Power Lost in the battery2`+.5,0]):

lmin2:=line([`Maximum Power Lost in the battery2`-.5,FP2((`Maximum Power Lost in the battery2`-.5))], [`Maximum Power Lost in the battery2`-.5,0]):

lcon2:=line([`Maximum Power Lost in the battery2`+.5,FP2((`Maximum Power Lost in the battery2`+.5))], [`Maximum Power Lost in the battery2`.5,FP2(`Maximum Power Lost in the battery2`-.5)]):

l2:=line([`Maximum Power Lost in the battery2`,0], [`Maximum Power Lost in the battery2`,2.4],linestyle=3):
display([F,G,H,J,lmax,lmin,lcon,l1,lmax2,lcon2,lmin2,l2]);
```



	Internal Resistence from Part 1 (ohms)	EMF from Part 1 (Volts)
1 9-Volt Battery	5.92±10.67%	8.361±3.68%
6 1.5-Volt Batteries	9.03±11.39%	9.15±5.45%
	Internal Resistence from Part 2	
1 9-Volt Battery	5.93±8.44%	
6 1.5-Volt Batteries	9.03±5.54%	
	1 9-Volt Battery	6 1.5-Volt Batteries
% Difference Between the two Parts	0.034%	0%

Uncertainty Diagrams



Conclusion:

Based on our results, we have concluded that our model accurately describes a Real Battery as a combination of an internal resistance and an ideal battery. The percent difference between the two parts is easily explained by the uncertainties involved; in the 6 1.5 batteries, the two values of the internal resistance was identical all the way to the fourth digit. Since these results follow from the basic principals of conservation of energy and self evident assumptions, we can, with reasonable safety, use this model to predict values of ε, $\Delta(V)$, r, R_{load}, I_{load} and $Power_{load}$ in one and two loop circuits involving resistors both in parallel and in series.

Our slight uncertainties, which account for the slight differences in our results, can be attributed to our ability to calculate the terminal voltage and the load current to only 3 decimal places. The slight resistance in the terminals and alligator clips can also add to the uncertainty.