The solid-state diode - Experiment 13

In[1]:=
```
<< CurveFit`
```

```
CurveFit for Mathematica v7.x thru v11.x, Version 1.96, 4/4/2018

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```

Note: The plot labels write the current units as A, but the data is in mA and the processing is done with this kept in mind. The plot labels have not been modified because this was noticed after all plots were completed and CurveFit does not save intermediary datasets, so recreating the plots would have been prohibitively time-consuming.

Testing the PN junction theory

We fit our data for the IV-curves of our diodes at room temperature and dry ice temperature to test how closely the data follows the theory presented in the lab manual. We also fit several regions of each dataset to test the theory in different regimes.

In[169]:=
```
(* We start by writing a function that commits the fit parameters for each region
 of each dataset to a list with structure {region, a, siga, b, sigb, χ̃²}. Region
 and χ̃² have to be entered manually, looking through CurveFit code,
documentation and variables does not show χ̃² being stored as a variable. *)

(* Initializing list *)
fitParam = {};
```

In[79]:=
```
(* Commiting fit parameters to list. *)
commitFit[region_, chisq_] := AppendTo[fitParam, {region, a, siga, b, sigb, chisq}];
```

In[6]:=
```
SetDirectory[StringJoin[NotebookDirectory[], "Diode"]];
```

Silicon diode - Room Temperature

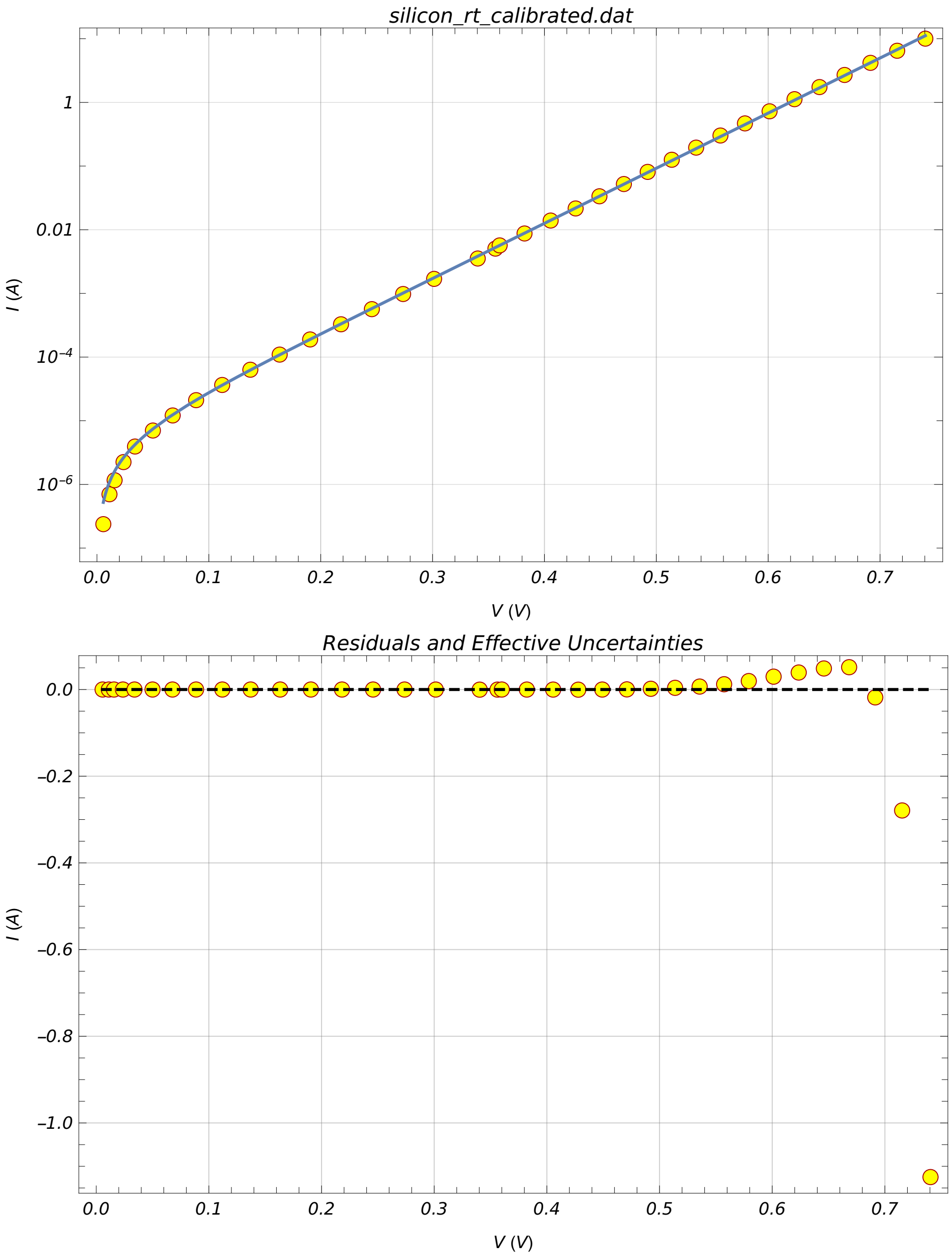
Whole dataset (bad points removed)

For all datasets we remove the lowest data point both for the high-current and low-current data. In lab we observed a discrepancy between measurements at the same current when the measurement corresponded to the lowest-current data point of both the high- and low- current datasets. There was no such discrepancy when the same measurement was not the lowest-current point on a dataset, indicating a hardware issue. Therefore we disregard both those points in the following analysis.

```
In[170]:= With[ {name = SystemDialogInput["FileOpen",
              {DataFileName, {"data files" -> {"*.dat", "*.mca"}, "all files" -> {"*"}}}]},
           If[ name =!= $Canceled,
            LoadFile[name]]
          ]

In[171]:= NRangeRemove /@ {1, 1, 17, 17}

In[172]:= With[{x = SetXRange[ LinearDataPlot[], Log -> False,
              Label -> "Set the X values for the range you wish to keep." ]},
           Print[x];

           XRangeKeep[Sequence @@ x]
          ]

          {-0.0154283, 0.755987}

          n= 36

          0 points removed.

In[173]:= DiodeFit[]
```

In[174]:=
```
LogDifferencePlot[FrameLabel → {"V (V)", "I (A)"}]
```

Out[174]=



$y(x) = a\ (\ \mathrm{Exp}[b\ x] - 1\ )$

$a=$	$b=$	
4.35498×10^{-6}	19.927	
$\sigma_a=$	$\sigma_b=$	$\chi^2/(n-2)=$
4.65343×10^{-9}	0.00180498	512.572

In[175]:=
```
commitFit[{-0.015428312500000001`, 0.7559873125`}, 512.5724700933897`];
```

Low voltage

In[176]:=
```
With[ {name = SystemDialogInput["FileOpen",
    {DataFileName, {"data files" -> {"*.dat", "*.mca"}, "all files" -> {"*"}}}]},
 If[ name =!= $Canceled,
  LoadFile[name]]
]
```

In[177]:=
```
NRangeRemove /@ {1, 1, 17, 17};
```

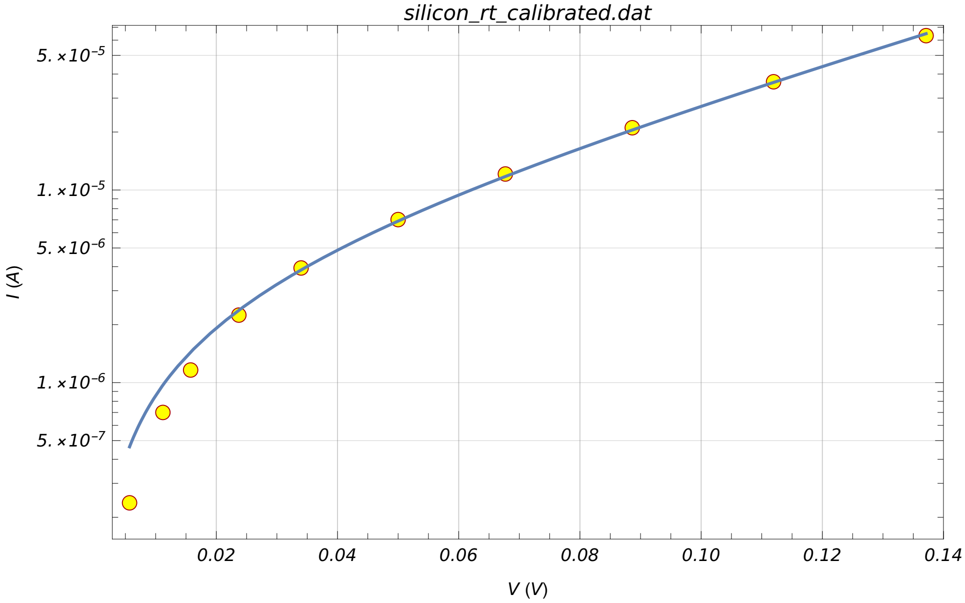
In[178]:=
```
With[{x = SetXRange[ LinearDataPlot[], Log -> False,
    Label -> "Set the X values for the range you wish to keep." ]},
 Print[x];

 XRangeKeep[Sequence @@ x]
]
```

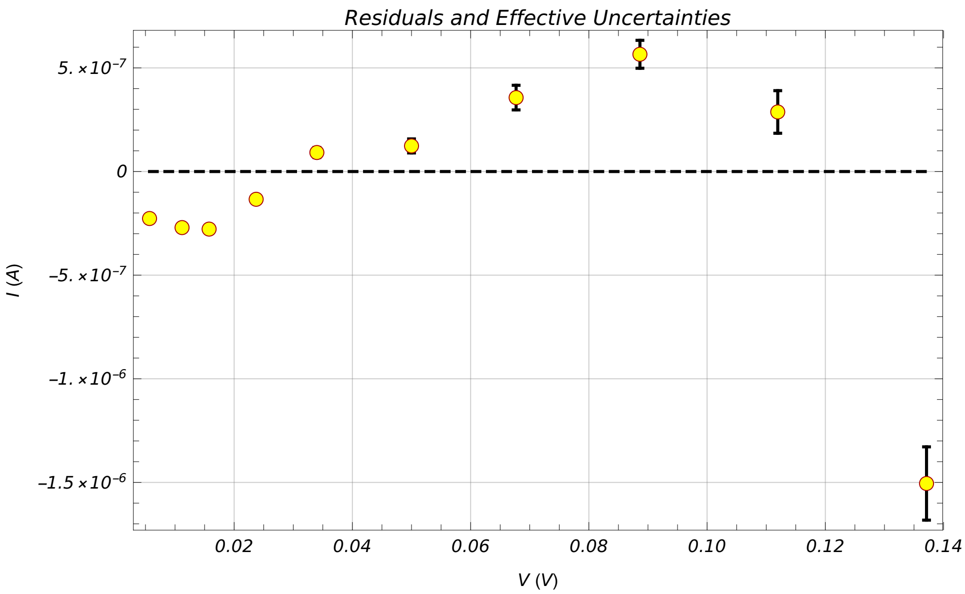
```
{-0.0154283, 0.1484}

n= 10

26 points removed.
```

In[179]:=
```
DiodeFit[]
```

In[180]:=
```
LogDifferencePlot[FrameLabel → {"V (V)", "I (A)"}]
```

Out[180]=





y(x) = a (Exp[b x] - 1)

a=	b=	
3.55954×10^{-6}	21.5518	
σ_a=	σ_b=	$\chi^2/(n-2)$=
2.24398×10^{-8}	0.0548155	170.084

In[181]:=
```
commitFit[{-0.015428312500000001`, 0.1484`}, 170.08393446581536`];
```

Medium voltage

In[182]:=
```
With[ {name = SystemDialogInput["FileOpen",
     {DataFileName, {"data files" -> {"*.dat", "*.mca"}, "all files" -> {"*"}}}]},
 If[ name =!= $Canceled,
  LoadFile[name]]
]
```

In[183]:=
```
NRangeRemove /@ {1, 1, 17, 17};
```

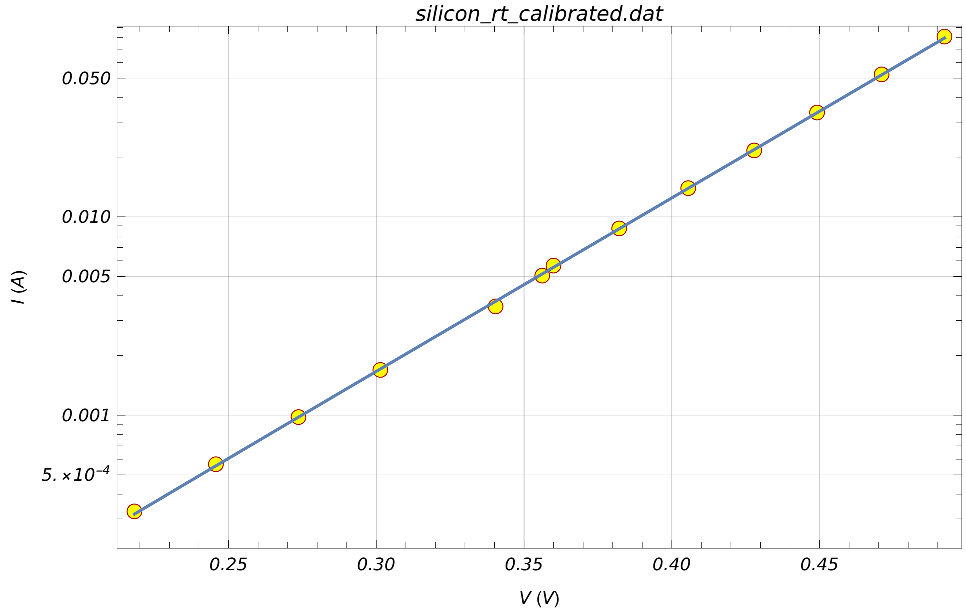
In[184]:=
```
With[{x = SetXRange[ LinearDataPlot[], Log -> False,
     Label -> "Set the X values for the range you wish to keep." ]},
 Print[x];

 XRangeKeep[Sequence @@ x]
]
```

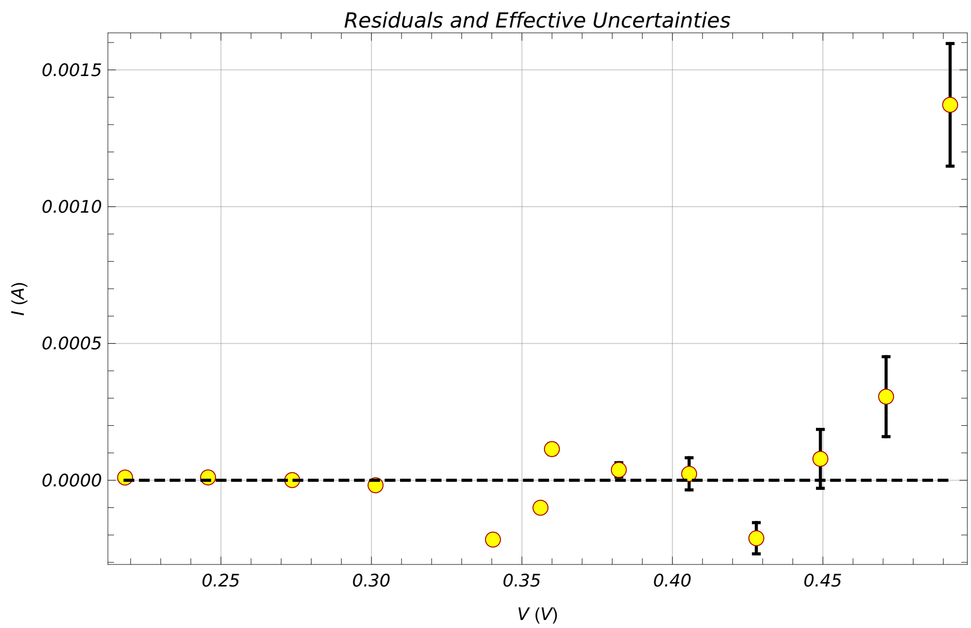
```
{0.206, 0.5024}

n= 13

23 points removed.
```

In[185]:=
```
DiodeFit[]
```

In[186]:= `LogDifferencePlot[FrameLabel → {"V (V)", "I (A)"}]`

Out[186]=





$y(x) = a\ (\ \mathrm{Exp}[b\ x] - 1\ )$

a= 3.99897×10^{-6}	b= 20.1083	
σ_a= 1.53239×10^{-8}	σ_b= 0.0101499	$\chi^2/(n-2)$= 41.4013

In[187]:= ``commitFit[{0.20600000000000002`, 0.5024000000000001`}, 41.401251771117565`];``

High voltage

In[188]:=
```
With[ {name = SystemDialogInput["FileOpen",
    {DataFileName, {"data files" -> {"*.dat", "*.mca"}, "all files" -> {"*"}}}]},
 If[ name =!= $Canceled,
  LoadFile[name]]
]
```

In[189]:=
```
NRangeRemove /@ {1, 1, 17, 17};
```

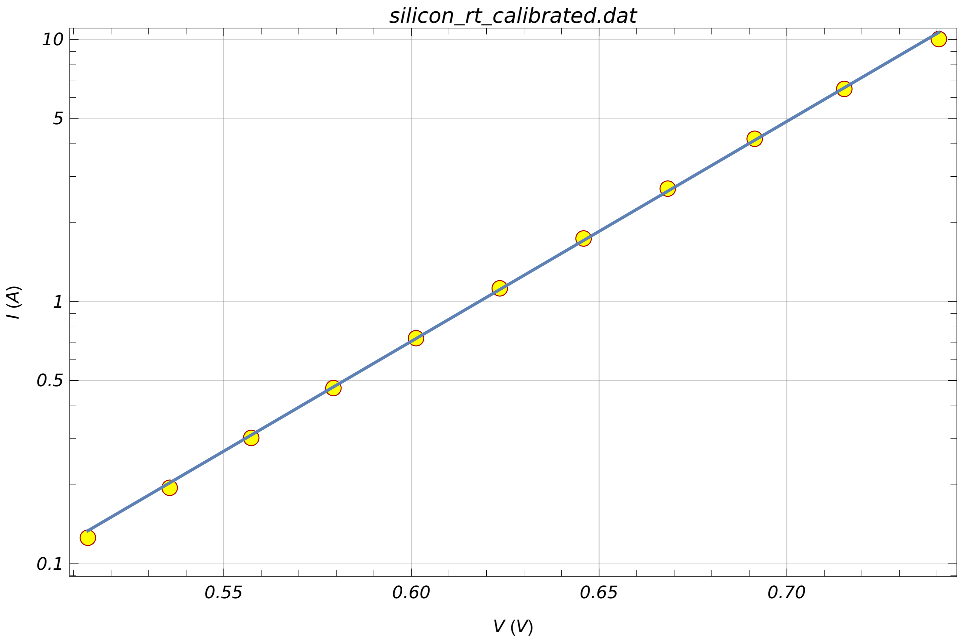
In[190]:=
```
With[{x = SetXRange[ LinearDataPlot[], Log -> False,
    Label -> "Set the X values for the range you wish to keep." ]},
 Print[x];

 XRangeKeep[Sequence @@ x]
]
```

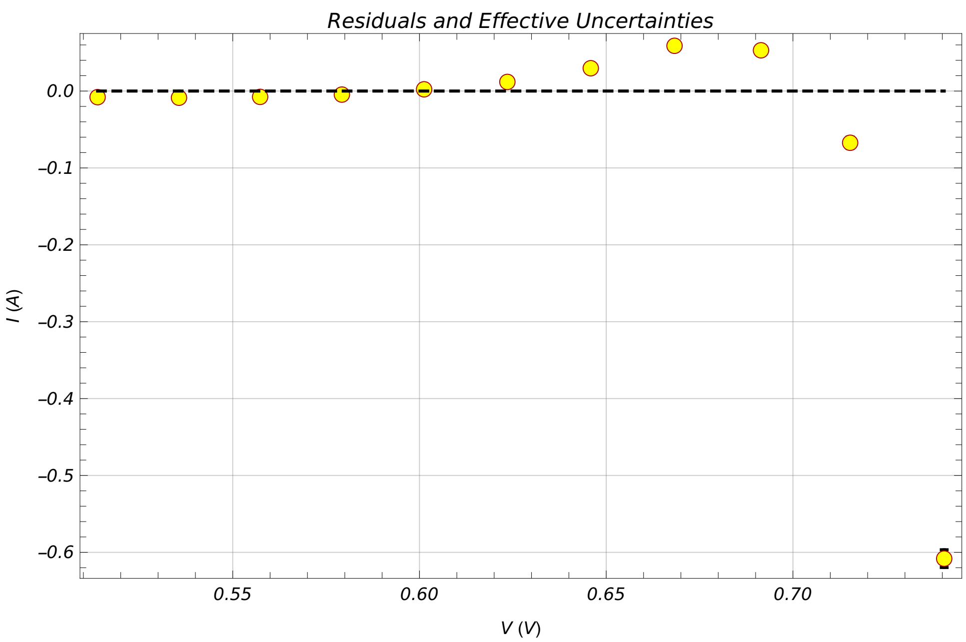
```
{0.501, 0.755987}

n= 11

25 points removed.
```

In[191]:=
```
DiodeFit[]
```

In[192]:=
```
LogDifferencePlot[FrameLabel → {"V (V)", "I (A)"}]
```

Out[192]=





y(x) = a (Exp[b x] − 1)

a=	b=	
6.56404×10^{-6}	19.3088	
σ_a=	σ_b=	$\chi^2/(n-2)$=
2.94935×10^{-8}	0.00677837	626.02

In[193]:=
```
commitFit[{0.501`, 0.7559873125`}, 626.0195037513873`];
```

In[194]:=
```
(* We store the collected data in a separate dataset for silicon
  diode at room temp and re-initialize fitParam for further use. *)
siliconRT = fitParam;
```

In[195]:=
```
fitParam = {};
```

Silicon diode - Dry Ice Temperature

Whole dataset (bad points removed)

In[197]:=
```
With[ {name = SystemDialogInput["FileOpen",
     {DataFileName, {"data files" -> {"*.dat", "*.mca"}, "all files" -> {"*"}}}]},
 If[ name =!= $Canceled,
  LoadFile[name]]
]
```

In[198]:=
```
NRangeRemove /@ {1, 1, 17, 17}
```

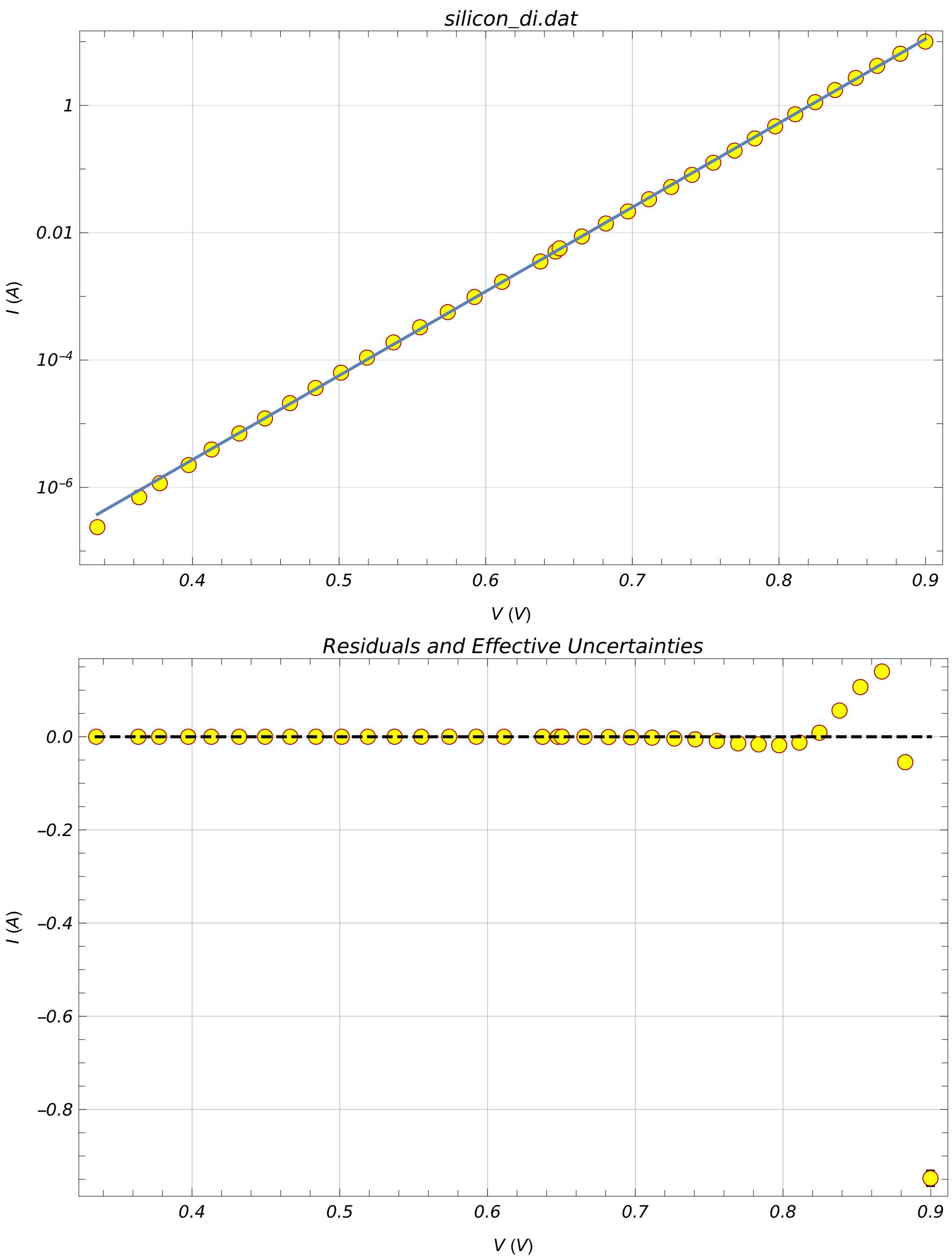
In[199]:=
```
With[{x = SetXRange[ LinearDataPlot[], Log -> False,
     Label -> "Set the X values for the range you wish to keep." ]},
 Print[x];

 XRangeKeep[Sequence @@ x]
]
```

```
{0.323086, 0.911654}

n= 36

0 points removed.
```

In[201]:=
```
DiodeFit[]
```

In[202]:= `LogDifferencePlot[FrameLabel → {"V (V)", "I (A)"}]`

Out[202]=



y(x) = a (Exp[b x] - 1)

a= 1.40303×10^{-11}	b= 30.4339	
σ_a= 3.64541×10^{-14}	σ_b= 0.00323305	$\chi^2/(n-2)$= 453.09

In[203]:= `commitFit[{0.32308562499999993`, 0.911654375`}, 453.08954952184655`];`

Low voltage

In[204]:=
```
With[ {name = SystemDialogInput["FileOpen",
     {DataFileName, {"data files" -> {"*.dat", "*.mca"}, "all files" -> {"*"}}}]},
 If[ name =!= $Canceled,
  LoadFile[name]]
]
```

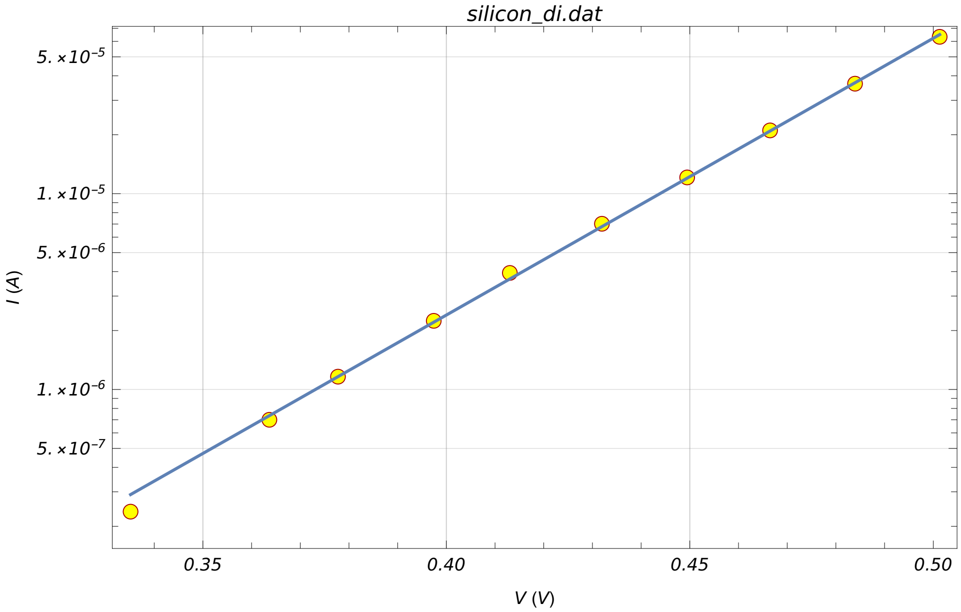
In[205]:=
```
NRangeRemove /@ {1, 1, 17, 17};
```

In[206]:=
```
With[{x = SetXRange[ LinearDataPlot[], Log -> False,
     Label -> "Set the X values for the range you wish to keep." ]},
 Print[x];

 XRangeKeep[Sequence @@ x]
]
```

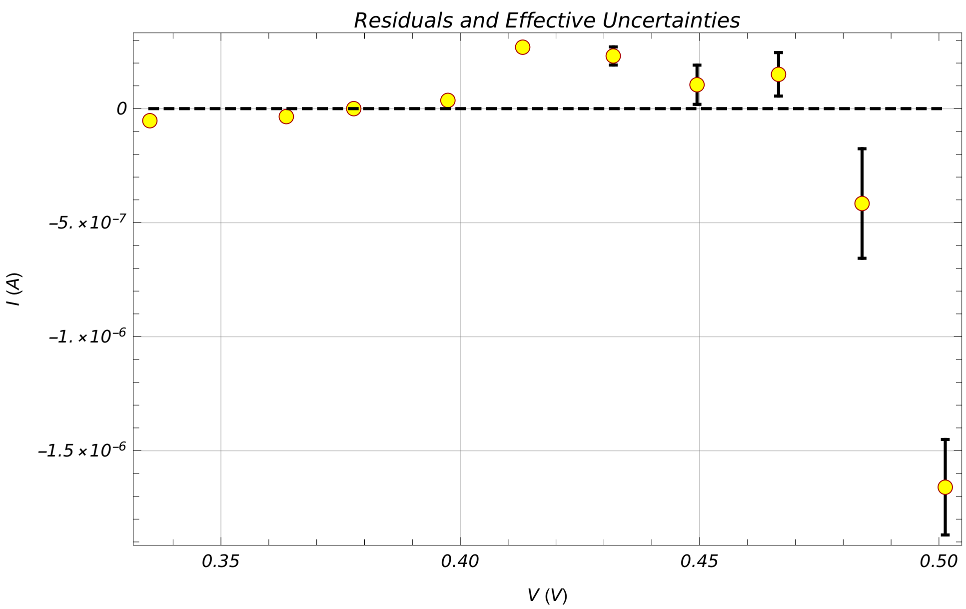
```
{0.323086, 0.5102}

n= 10

26 points removed.
```

In[207]:=
```
DiodeFit[]
```

In[208]:=
```
LogDifferencePlot[FrameLabel → {"V (V)", "I (A)"}]
```



Out[208]=



y(x) = a (Exp[b x] - 1)

a=	b=	
5.30356×10^{-12}	32.5559	
σ_a=	σ_b=	$\chi^2/(n-2)$ =
8.93198×10^{-14}	0.0372247	92.7384

In[209]:=
```
commitFit[{0.32308562499999993`, 0.5102`}, 92.73844942065703`];
```

Medium voltage

In[210]:=
```
With[ {name = SystemDialogInput["FileOpen",
    {DataFileName, {"data files" -> {"*.dat", "*.mca"}, "all files" -> {"*"}}}]},
 If[ name =!= $Canceled,
  LoadFile[name]]
]
```

In[211]:=
```
NRangeRemove /@ {1, 1, 17, 17};
```

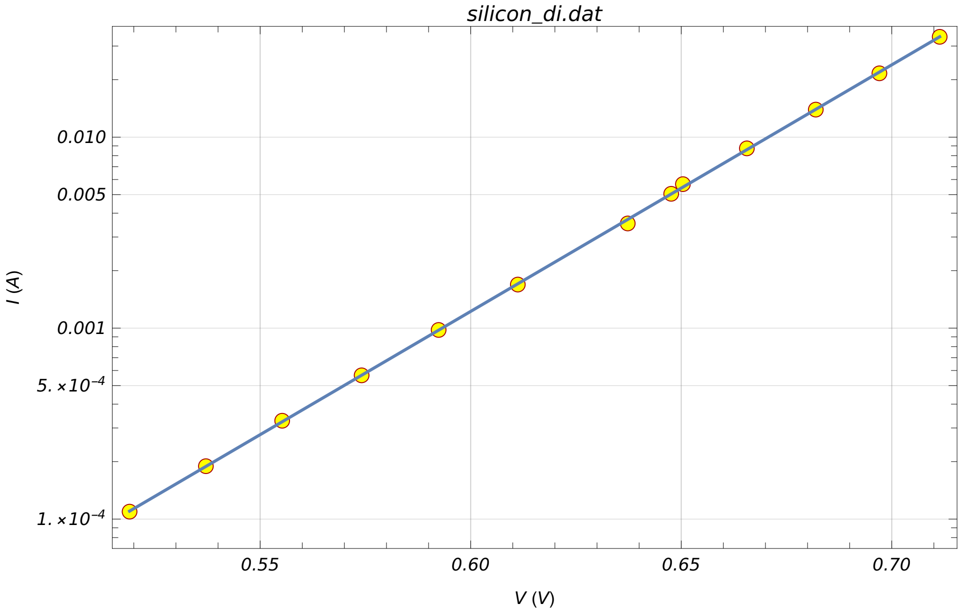
In[212]:=
```
With[{x = SetXRange[ LinearDataPlot[], Log -> False,
    Label -> "Set the X values for the range you wish to keep." ]},
 Print[x];

 XRangeKeep[Sequence @@ x]
]
```

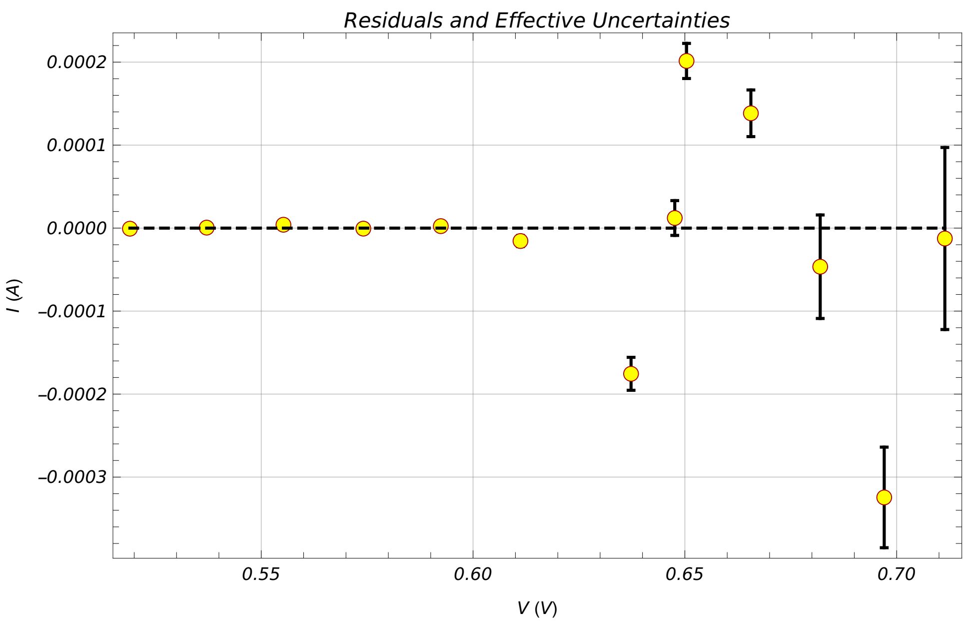
```
{0.5082, 0.7202}

n= 13

23 points removed.
```

In[213]:=
```
DiodeFit[]
```

In[214]:=
```
LogDifferencePlot[FrameLabel → {"V (V)", "I (A)"}]
```

Out[214]=





y(x) = a (Exp[b x] - 1)

a=	b=	
2.19361×10^{-11}	29.7281	
σ_a=	σ_b=	$\chi^2/(n-2)$=
2.20064×10^{-13}	0.0158754	21.9023

In[215]:=
```
commitFit[{0.5082`, 0.7202000000000001`}, 21.90234094658127`];
```

High voltage

In[216]:=
```
With[ {name = SystemDialogInput["FileOpen",
    {DataFileName, {"data files" -> {"*.dat", "*.mca"}, "all files" -> {"*"}}}]},
 If[ name =!= $Canceled,
  LoadFile[name]]
]

NRangeRemove /@ {1, 1, 17, 17};
```

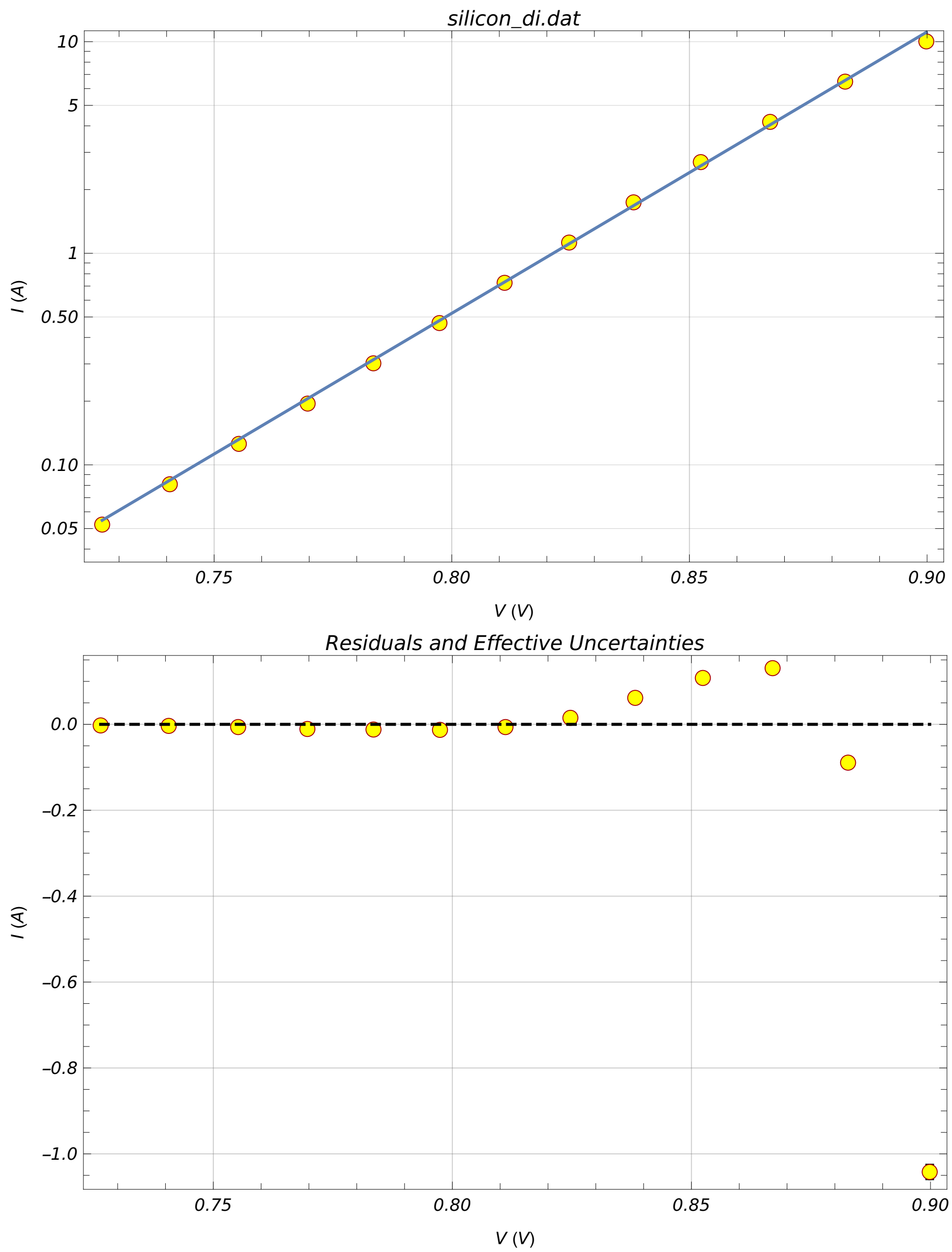
In[217]:=
```
With[{x = SetXRange[ LinearDataPlot[], Log -> False,
    Label -> "Set the X values for the range you wish to keep." ]},
 Print[x];

 XRangeKeep[Sequence @@ x]
]
```

```
{0.7176, 0.911867}

n= 13

27 points removed.
```

In[218]:=
```
DiodeFit[]
```

In[219]:=
```
LogDifferencePlot[FrameLabel → {"V (V)", "I (A)"}]
```

Out[219]=



y(x) = a (Exp[b x] - 1)

a= 1.19161×10^{-11}	b= 30.625	
σ_a= 1.24639×10^{-13}	σ_b= 0.0122291	$\chi^2/(n-2)$= 785.199

In[220]:=
```
commitFit[{0.7176`, 0.9118667291666667`}, 785.1993496718917`];
```

In[221]:=
```
(* We store the collected data in a separate dataset for silicon
  diode at room temp and re-initialize fitParam for further use. *)
siliconDI = fitParam;
```

In[222]:=
```
fitParam = {};
```

Germanium diode - Room Temperature

Whole dataset (bad points removed)

In[227]:=
```
With[ {name = SystemDialogInput["FileOpen",
     {DataFileName, {"data files" -> {"*.dat", "*.mca"}, "all files" -> {"*"}}}]},
 If[ name =!= $Canceled,
  LoadFile[name]]
]
```

In[228]:=
```
NRangeRemove /@ {1, 1, 17, 17}
```

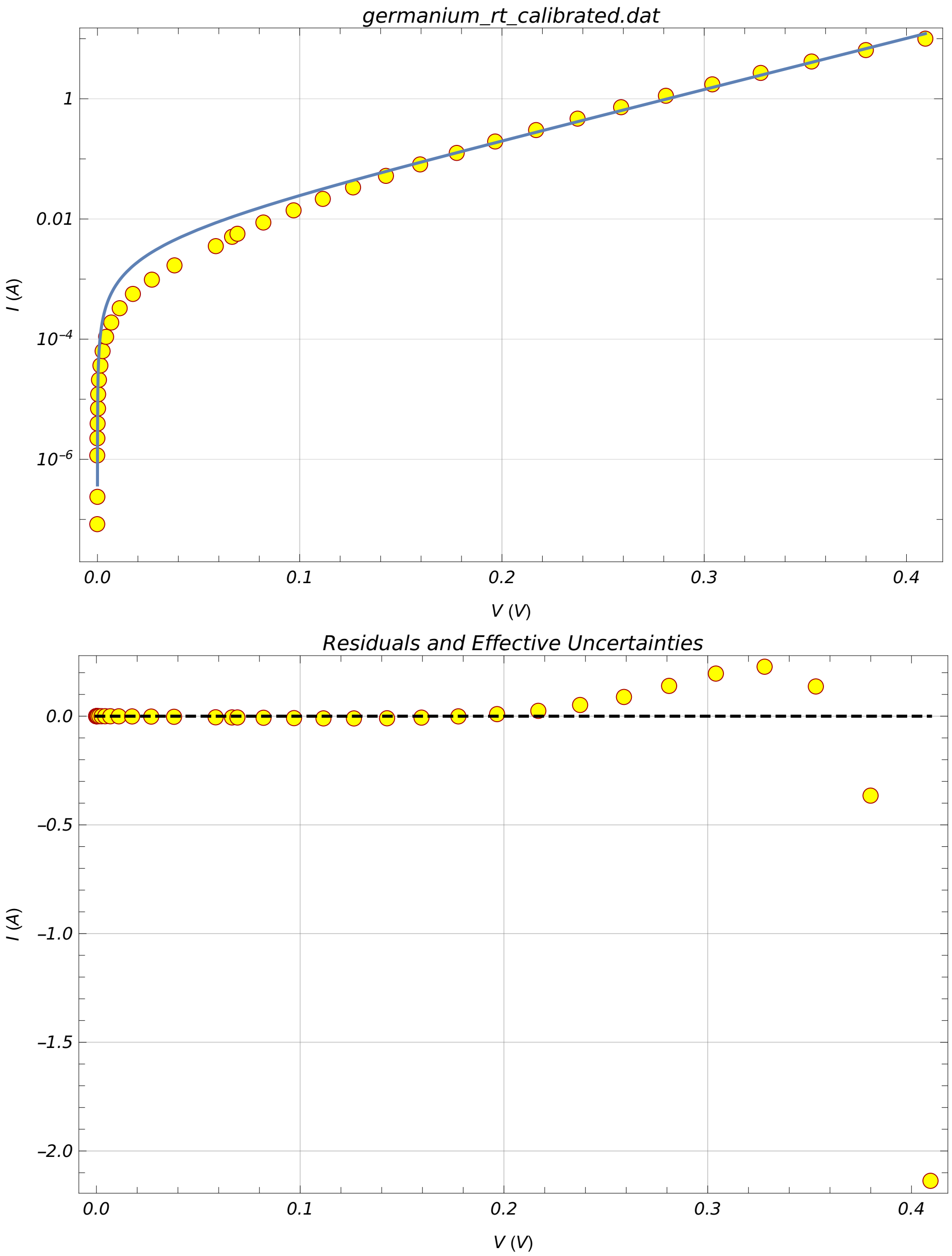
In[229]:=
```
With[{x = SetXRange[ LinearDataPlot[], Log -> False,
     Label -> "Set the X values for the range you wish to keep." ]},
 Print[x];

 XRangeKeep[Sequence @@ x]
]
```

```
{-0.00877563, 0.417906}

n= 36

0 points removed.
```

In[230]:=
```
DiodeFit[]
```

In[231]:=
```
LogDifferencePlot[FrameLabel → {"V (V)", "I (A)"}]
```

Out[231]=



y(x) = a (Exp[b x] - 1)

a= 0.00403687	b= 19.5712	
σ_a= 5.81426×10^{-6}	σ_b= 0.00438953	$\chi^2/(n-2)$= 10170.8

In[232]:=
```
commitFit[{-0.008775625`, 0.41790562499999995`}, 10170.77697297076`];
```

Low voltage

In[233]:=
```
With[ {name = SystemDialogInput["FileOpen",
     {DataFileName, {"data files" -> {"*.dat", "*.mca"}, "all files" -> {"*"}}}]},
 If[ name =!= $Canceled,
  LoadFile[name]]
]
```

In[234]:=
```
NRangeRemove /@ {1, 1, 17, 17};
```

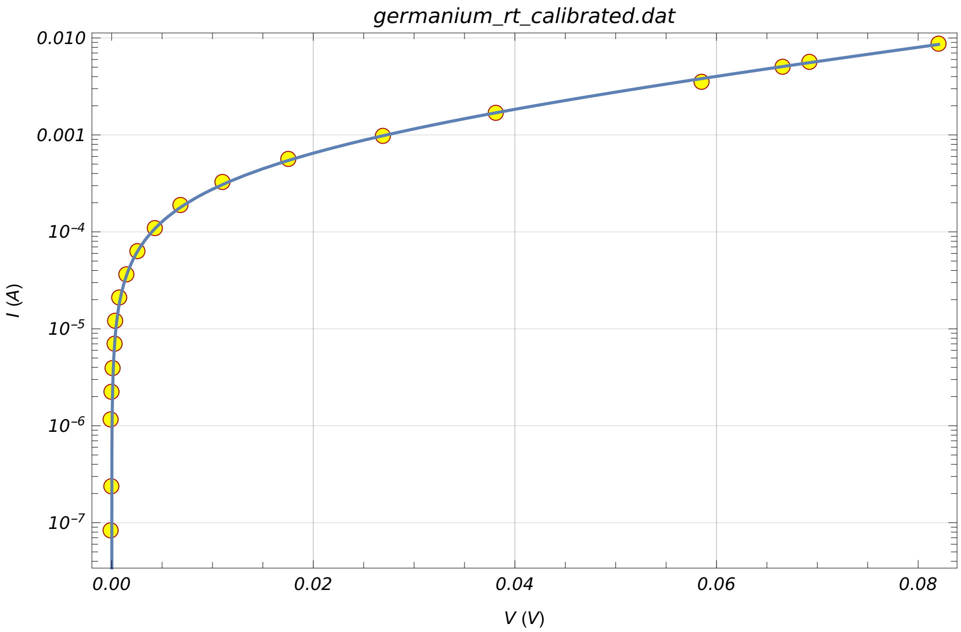
In[235]:=
```
With[{x = SetXRange[ LinearDataPlot[], Log -> False,
     Label -> "Set the X values for the range you wish to keep." ]},
 Print[x];

 XRangeKeep[Sequence @@ x]
]
```

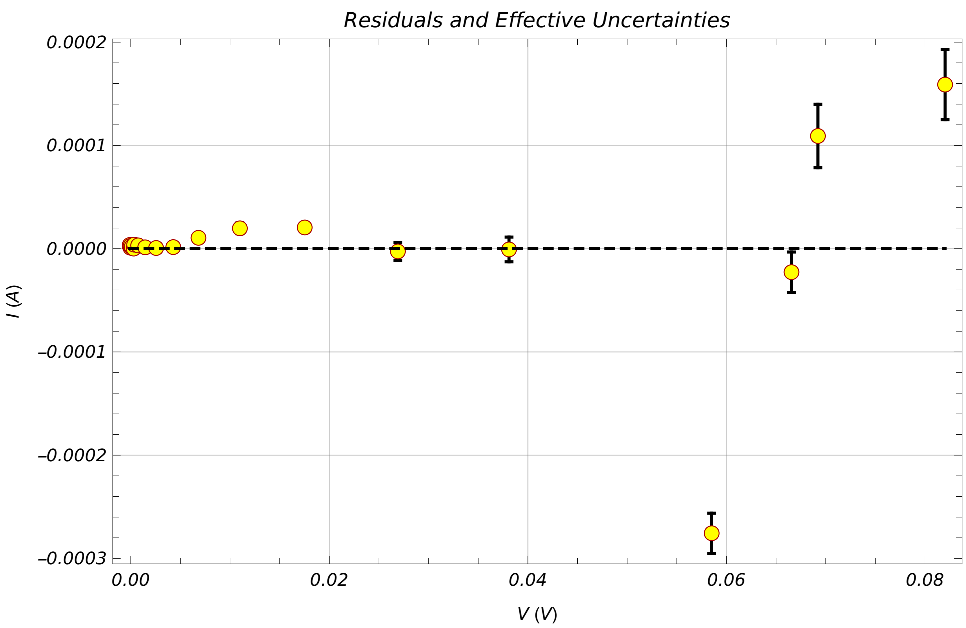
```
{-0.00877563, 0.0908}

n= 20

16 points removed.
```

In[236]:=
```
DiodeFit[]
```

In[237]:= `LogDifferencePlot[FrameLabel → {"V (V)", "I (A)"}]`

Out[237]=





y(x) = a (Exp[b x] - 1)

a= 0.000777601	b= 30.326	
σ_a= 7.22748×10^{-6}	σ_b= 0.124108	$\chi^2/(n-2)$= 16.2077

In[238]:= `commitFit[{-0.008775625`, 0.0908`}, 16.207728611078206`];`

Medium voltage

In[239]:=
```
With[ {name = SystemDialogInput["FileOpen",
    {DataFileName, {"data files" -> {"*.dat", "*.mca"}, "all files" -> {"*"}}}]},
 If[ name =!= $Canceled,
  LoadFile[name]]
]
```

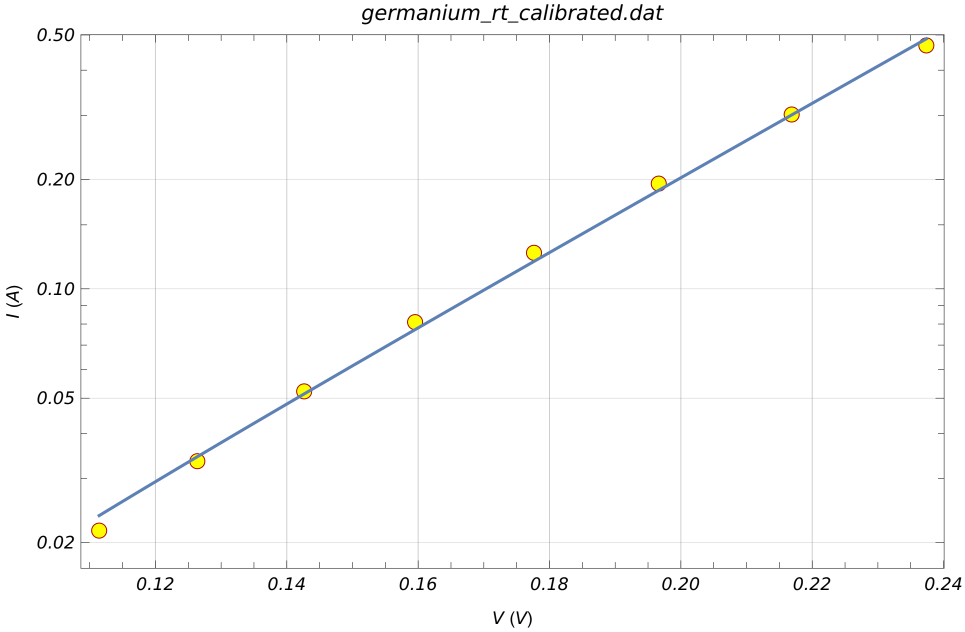
In[240]:=
```
NRangeRemove /@ {1, 1, 17, 17};
```

In[241]:=
```
With[{x = SetXRange[ LinearDataPlot[], Log -> False,
    Label -> "Set the X values for the range you wish to keep." ]},
 Print[x];

 XRangeKeep[Sequence @@ x]
]
```

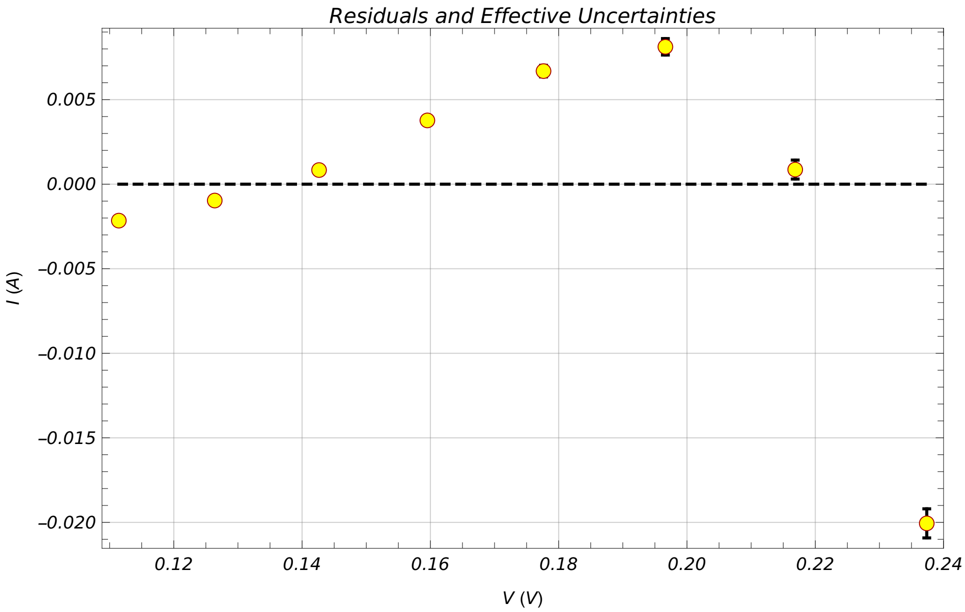
```
{0.104, 0.2466}

n= 8

28 points removed.
```

In[242]:=
```
DiodeFit[]
```

In[243]:=
```
LogDifferencePlot[FrameLabel → {"V (V)", "I (A)"}]
```



Out[243]=



y(x) = a (Exp[b x] - 1)

a= 0.00188447	b= 23.4242	
σ_a= 7.52439×10^{-6}	σ_b= 0.0209988	$\chi^2/(n-2)$= 411.611

In[244]:=
```
commitFit[{0.10400000000000001`, 0.2466`}, 411.61120822450107`];
```

High voltage

In[245]:=
```
With[ {name = SystemDialogInput["FileOpen",
     {DataFileName, {"data files" -> {"*.dat", "*.mca"}, "all files" -> {"*"}}}]},
 If[ name =!= $Canceled,
  LoadFile[name]]
]
```

In[246]:=
```
NRangeRemove /@ {1, 1, 17, 17};
```

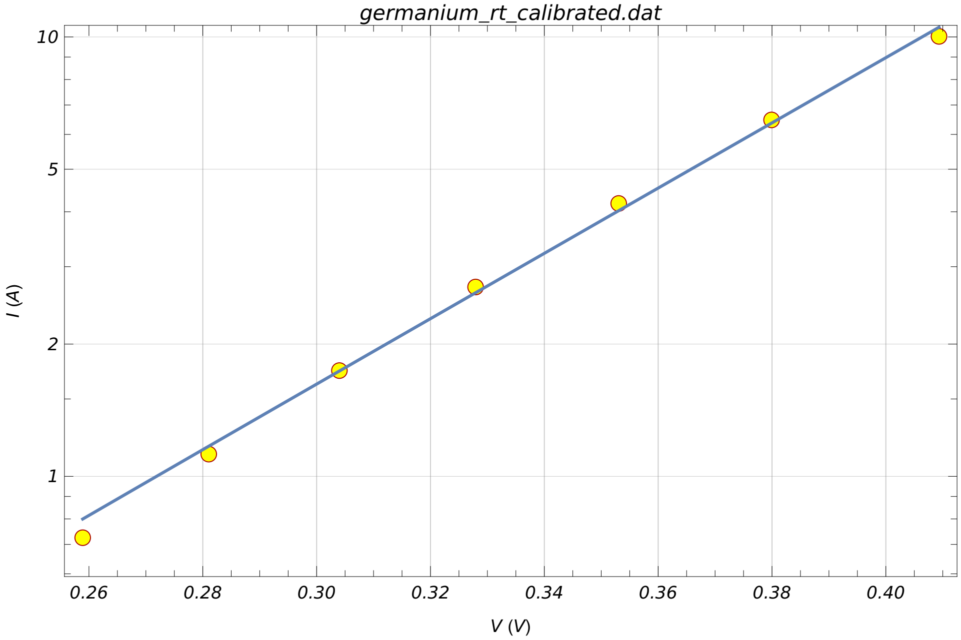
In[247]:=
```
With[{x = SetXRange[ LinearDataPlot[], Log -> False,
     Label -> "Set the X values for the range you wish to keep." ]},
 Print[x];

 XRangeKeep[Sequence @@ x]
]
```

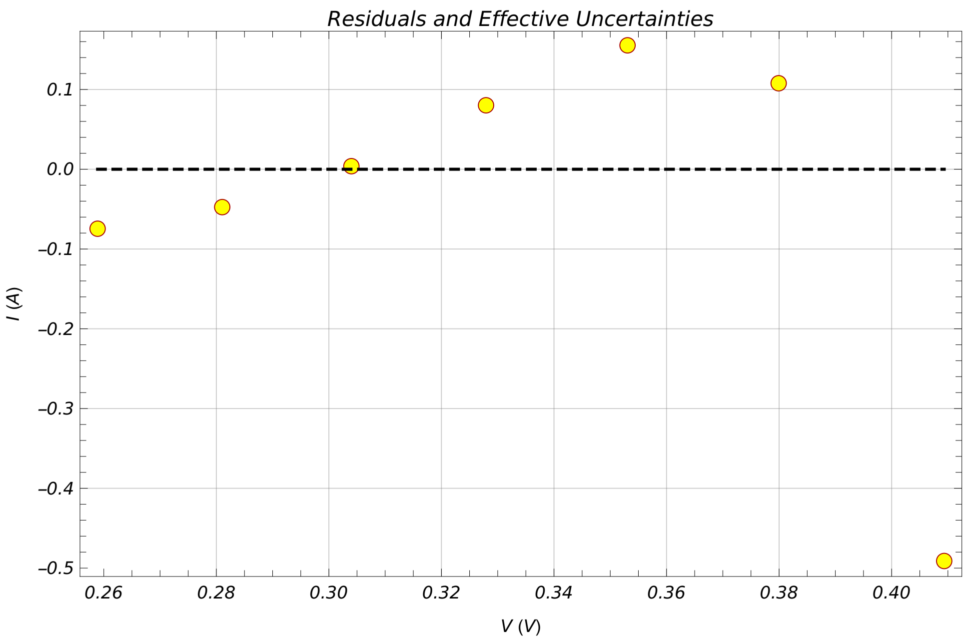
```
{0.2473, 0.417906}

n= 7

29 points removed.
```

In[248]:=
```
DiodeFit[]
```

In[249]:=
```
LogDifferencePlot[FrameLabel → {"V (V)", "I (A)"}]
```

Out[249]=





y(x) = a (Exp[b x] - 1)

a= 0.0097824	b= 17.0552	
σ_a= 0.0000209918	σ_b= 0.00600576	$\chi^2/(n-2)$= 4168.84

In[250]:=
```
commitFit[{0.2473`, 0.41790562499999995`}, 4168.841482732459`];
```

In[251]:=
```
(* We store the collected data in a separate dataset for silicon
  diode at room temp and re-initialize fitParam for further use. *)
germaniumRT = fitParam;
```

In[252]:=
```
fitParam = {};
```

Germanium diode - Dry Ice Temperature

Whole dataset (bad points removed)

In[255]:=
```
With[ {name = SystemDialogInput["FileOpen",
     {DataFileName, {"data files" -> {"*.dat", "*.mca"}, "all files" -> {"*"}}}]},
 If[ name =!= $Canceled,
  LoadFile[name]]
]
```

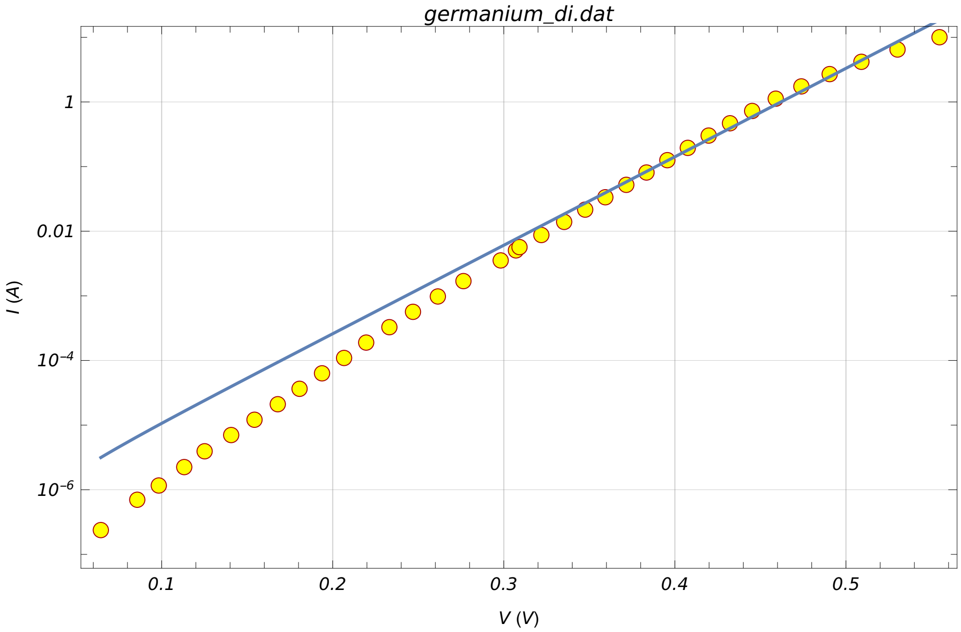
In[256]:=
```
NRangeRemove /@ {1, 1, 17, 17};
```

In[257]:=
```
With[{x = SetXRange[ LinearDataPlot[], Log -> False,
     Label -> "Set the X values for the range you wish to keep." ]},
 Print[x];

 XRangeKeep[Sequence @@ x]
]
```

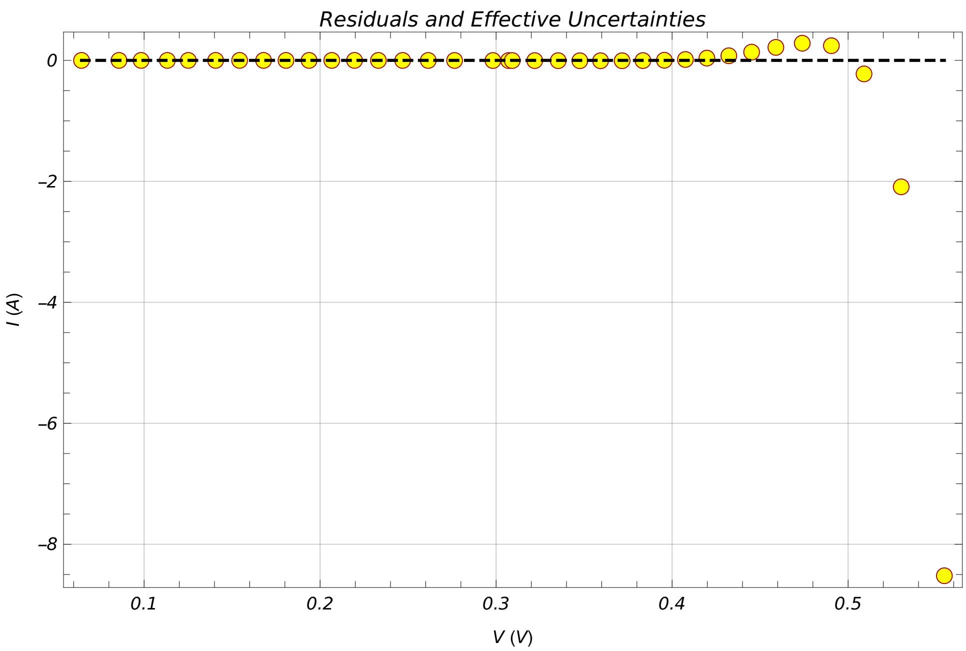
```
{0.0528011, 0.564946}

n= 36

0 points removed.
```

In[260]:=
```
DiodeFit[]
```

In[261]:= `LogDifferencePlot[FrameLabel → {"V (V)", "I (A)"}]`



Out[261]=



y(x) = a (Exp[b x] - 1)

a= 4.75907×10^{-7}	b= 31.5107	
σ_a= 1.21462×10^{-9}	σ_b= 0.00551868	$\chi^2/(n-2)$ = 43 186.9

In[262]:= `commitFit[{0.05280110416666667`, 0.5649458958333333`}, 43186.93739403151`];`

Low voltage

In[263]:=
```
With[ {name = SystemDialogInput["FileOpen",
    {DataFileName, {"data files" -> {"*.dat", "*.mca"}, "all files" -> {"*"}}}]},
 If[ name =!= $Canceled,
  LoadFile[name]]
]
```

In[264]:=
```
NRangeRemove /@ {1, 1, 17, 17};
```

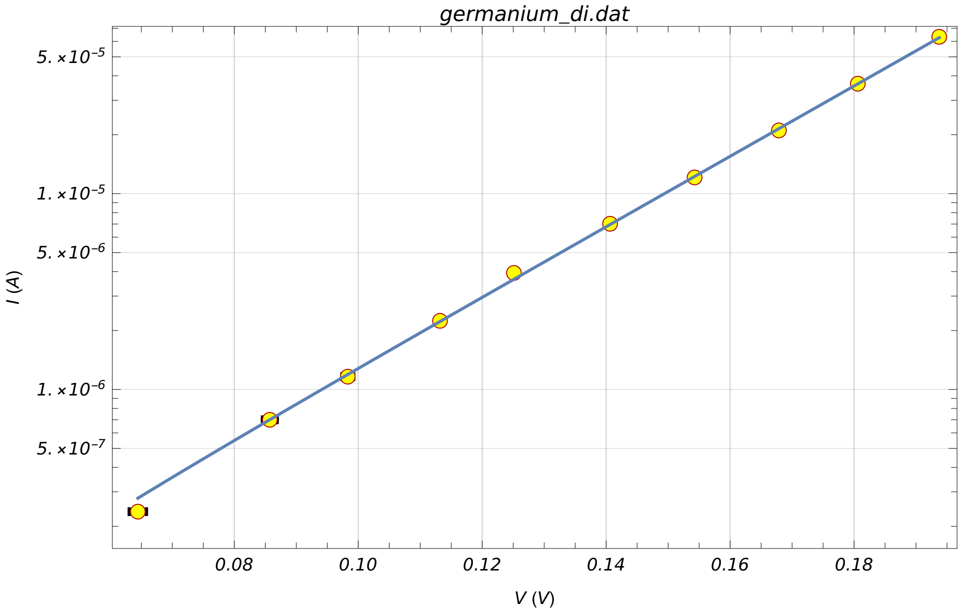
In[265]:=
```
With[{x = SetXRange[ LinearDataPlot[], Log -> False,
    Label -> "Set the X values for the range you wish to keep." ]},
 Print[x];

 XRangeKeep[Sequence @@ x]
]
```

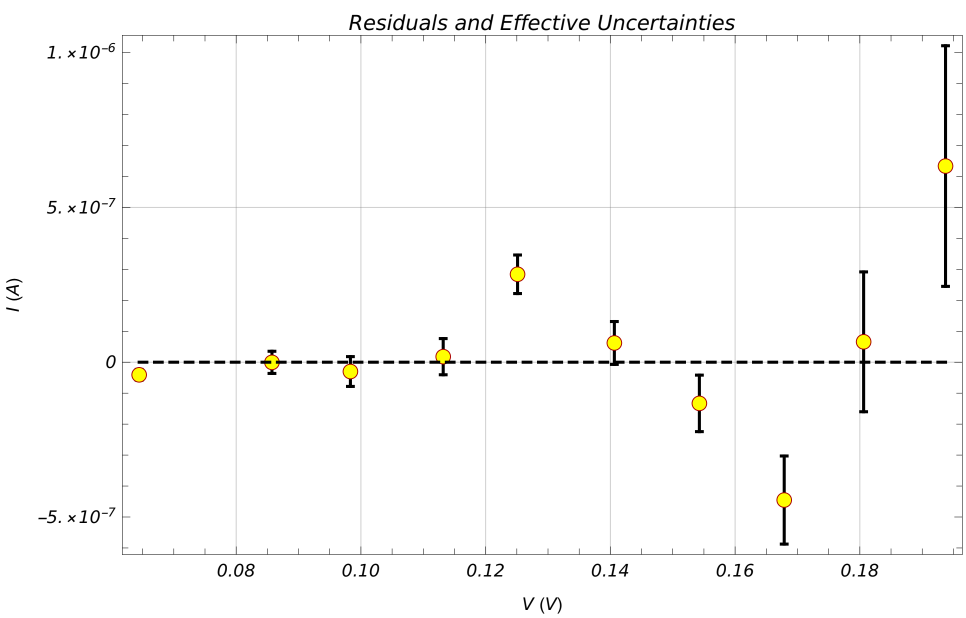
```
{0.0528011, 0.1999}

n= 10

26 points removed.
```

In[266]:=
```
DiodeFit[]
```

In[267]:= `LogDifferencePlot[FrameLabel → {"V (V)", "I (A)"}]`

Out[267]=





y(x) = a (Exp[b x] − 1)

a=	b=	
2.08452×10^{-8}	41.3377	
σ_a=	σ_b=	$\chi^2/(n-2)$ =
5.04666×10^{-10}	0.140402	5.28525

In[268]:= `commitFit[{0.05280110416666667`, 0.19990000000000002`}, 5.285252955291375`];`

Medium voltage

In[271]:=
```
With[ {name = SystemDialogInput["FileOpen",
    {DataFileName, {"data files" -> {"*.dat", "*.mca"}, "all files" -> {"*"}}}]},
 If[ name =!= $Canceled,
  LoadFile[name]]
]
```

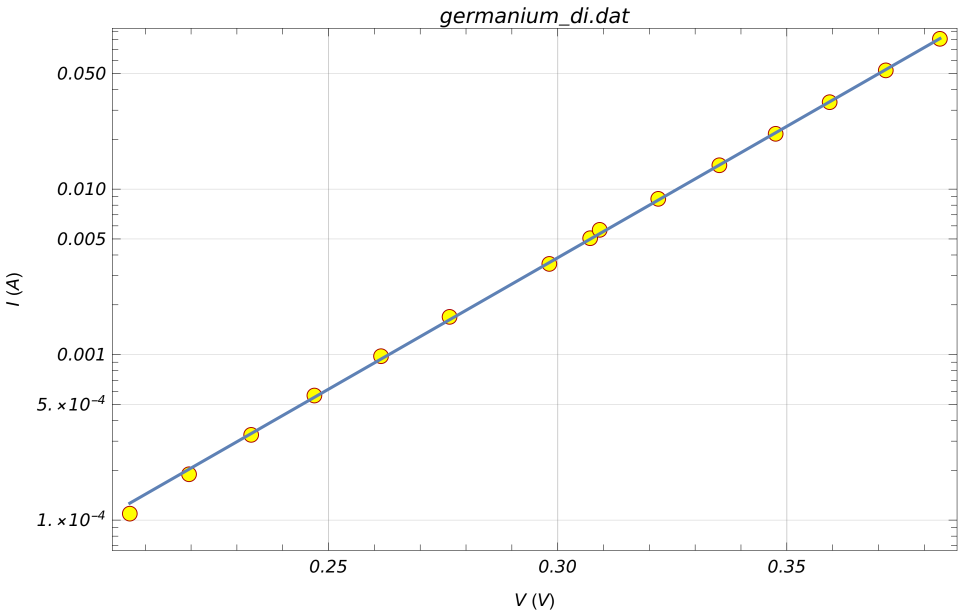
In[272]:=
```
NRangeRemove /@ {1, 1, 17, 17};
```

In[273]:=
```
With[{x = SetXRange[ LinearDataPlot[], Log -> False,
    Label -> "Set the X values for the range you wish to keep." ]},
 Print[x];

 XRangeKeep[Sequence @@ x]
]
```

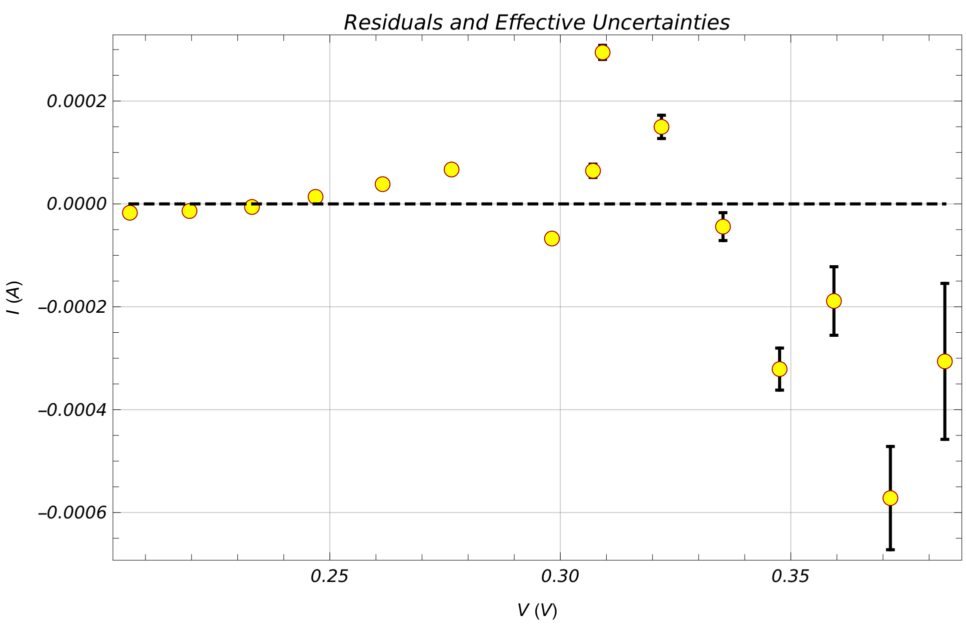
```
{0.2008, 0.3901}

n= 15

21 points removed.
```

In[274]:=
```
DiodeFit[]
```

In[275]:= `LogDifferencePlot[FrameLabel → {"V (V)", "I (A)"}]`



Out[275]=



y(x) = a (Exp[b x] − 1)

a=	b=	
6.61959×10^{-8}	36.5684	
σ_a=	σ_b=	$\chi^2/(n-2)$=
3.635×10^{-10}	0.0163476	139.803

In[276]:= `commitFit[{0.2008`, 0.3901`}, 139.80254205738402`];`

High voltage

In[739]:=
```
With[ {name = SystemDialogInput["FileOpen",
    {DataFileName, {"data files" -> {"*.dat", "*.mca"}, "all files" -> {"*"}}}]},
 If[ name =!= $Canceled,
  LoadFile[name]]
]
```

In[740]:=
```
NRangeRemove /@ {1, 1, 17, 17};
```

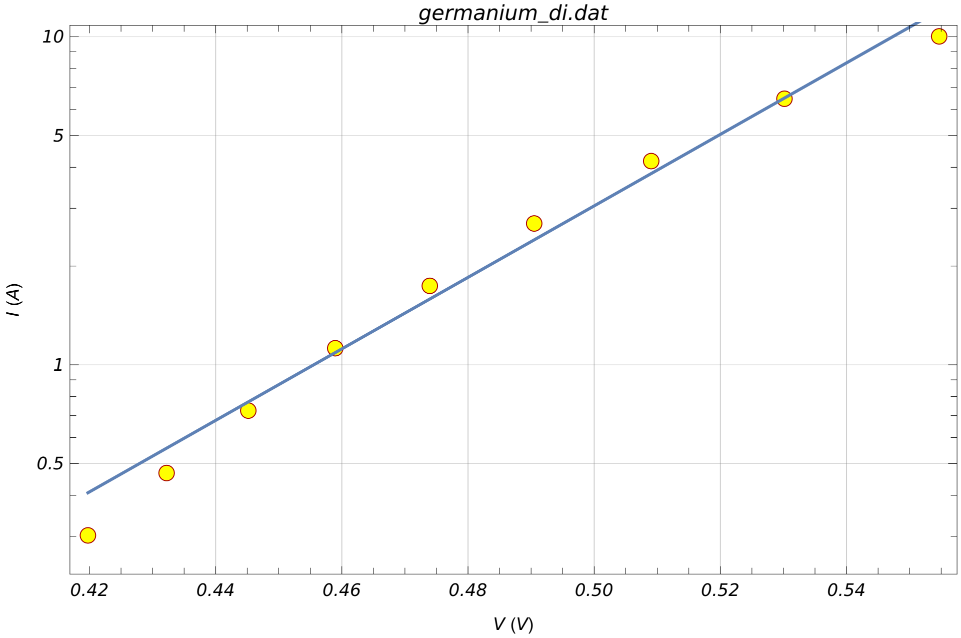
In[741]:=
```
With[{x = SetXRange[ LinearDataPlot[], Log -> False,
    Label -> "Set the X values for the range you wish to keep."]},
 Print[x];

 XRangeKeep[Sequence @@ x]
]
```

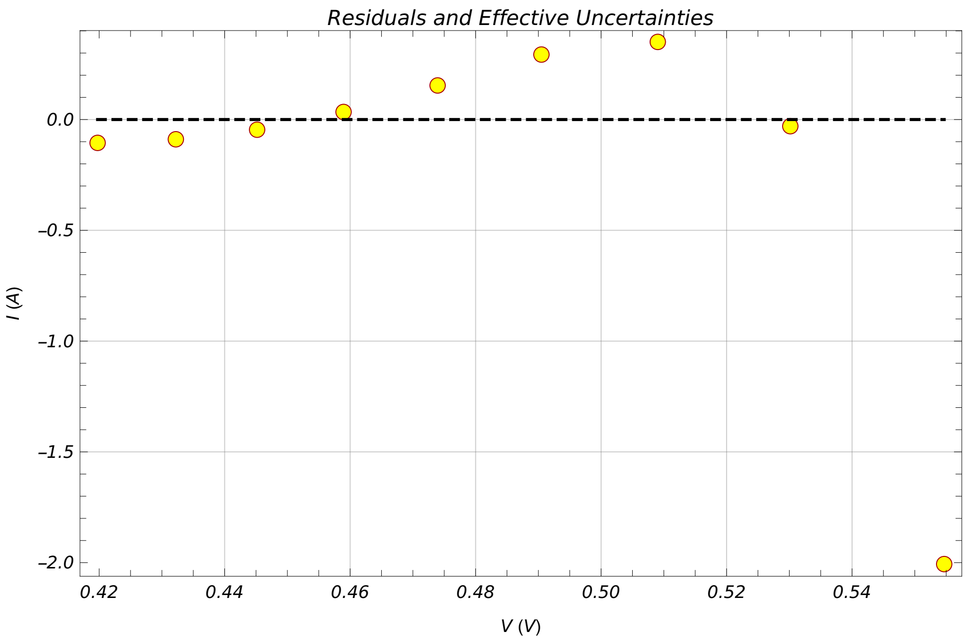
```
{0.4148, 0.564946}
n= 9
27 points removed.
```

In[742]:=
```
DiodeFit[]
```

In[743]:=
```
LogDifferencePlot[FrameLabel → {"V (V)", "I (A)"}]
```

Out[743]=





y(x) = a (Exp[b x] − 1)

a= 0.0000108504	b= 25.0939	
σ_a= 3.02275×10^{-8}	σ_b= 0.00560288	$\chi^2/(n-2)$= 45693.8

In[747]:=
```
commitFit[{0.4148`, 0.5649458958333333`}, 45693.79129063999`];
```

In[•]:=
```
(* We store the collected data in a separate dataset for silicon
   diode at room temp and re-initialize fitParam for further use. *)
germaniumDI = fitParam;
```

In[750]:=
```
fitParam = {};
```

Transistor - Room Temperature

Whole dataset (bad points removed)

In[287]:=
```
With[ {name = SystemDialogInput["FileOpen",
     {DataFileName, {"data files" -> {"*.dat", "*.mca"}, "all files" -> {"*"}}}]},
 If[ name =!= $Canceled,
  LoadFile[name]]
]
```

In[288]:=
```
NRangeRemove /@ {1, 1, 17, 17};
```

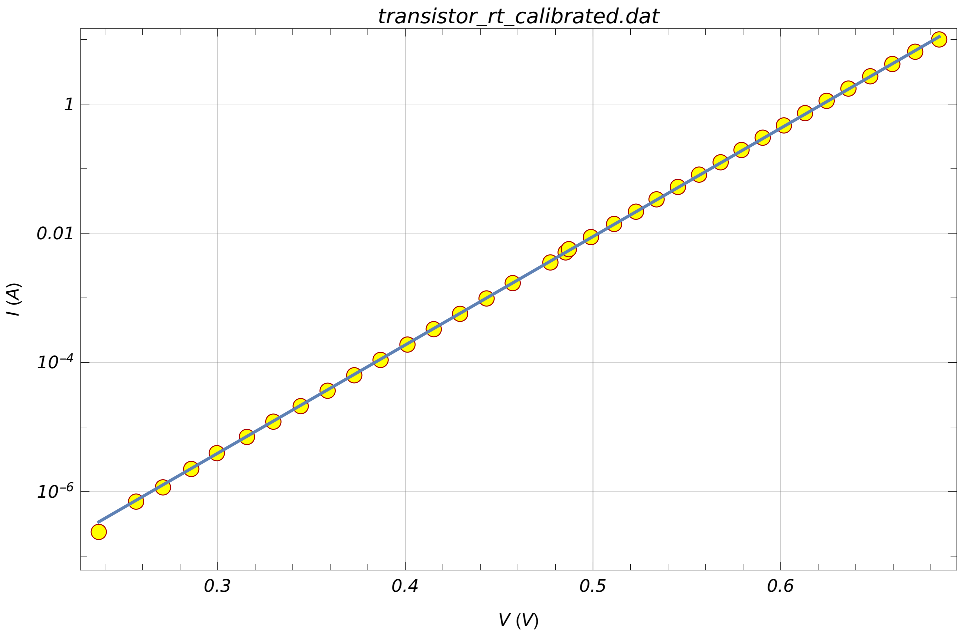
In[289]:=
```
With[{x = SetXRange[ LinearDataPlot[], Log -> False,
     Label -> "Set the X values for the range you wish to keep." ]},
 Print[x];

 XRangeKeep[Sequence @@ x]
]
```

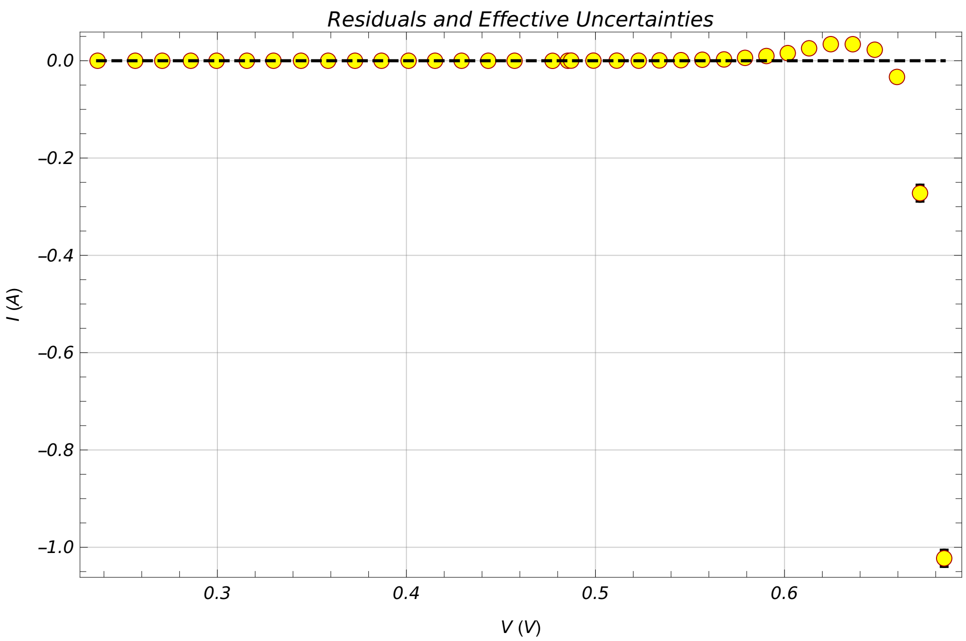
```
{0.22701, 0.693855}

n= 36

0 points removed.
```

In[290]:=
```
DiodeFit[]
```

In[291]:= `LogDifferencePlot[FrameLabel → {"V (V)", "I (A)"}]`

Out[291]=





y(x) = a (Exp[b x] - 1)

a=	b=	
3.64202×10^{-11}	38.6257	
σ_a=	σ_b=	$\chi^2/(n-2)$=
1.15854×10^{-13}	0.00530517	204.849

In[292]:= `commitFit[{0.22701010416666667`, 0.6938548958333333`}, 204.84853397967123`];`

Low voltage

In[293]:=
```
With[ {name = SystemDialogInput["FileOpen",
    {DataFileName, {"data files" -> {"*.dat", "*.mca"}, "all files" -> {"*"}}}]},
 If[ name =!= $Canceled,
  LoadFile[name]]
]
```

In[294]:=
```
NRangeRemove /@ {1, 1, 17, 17};
```

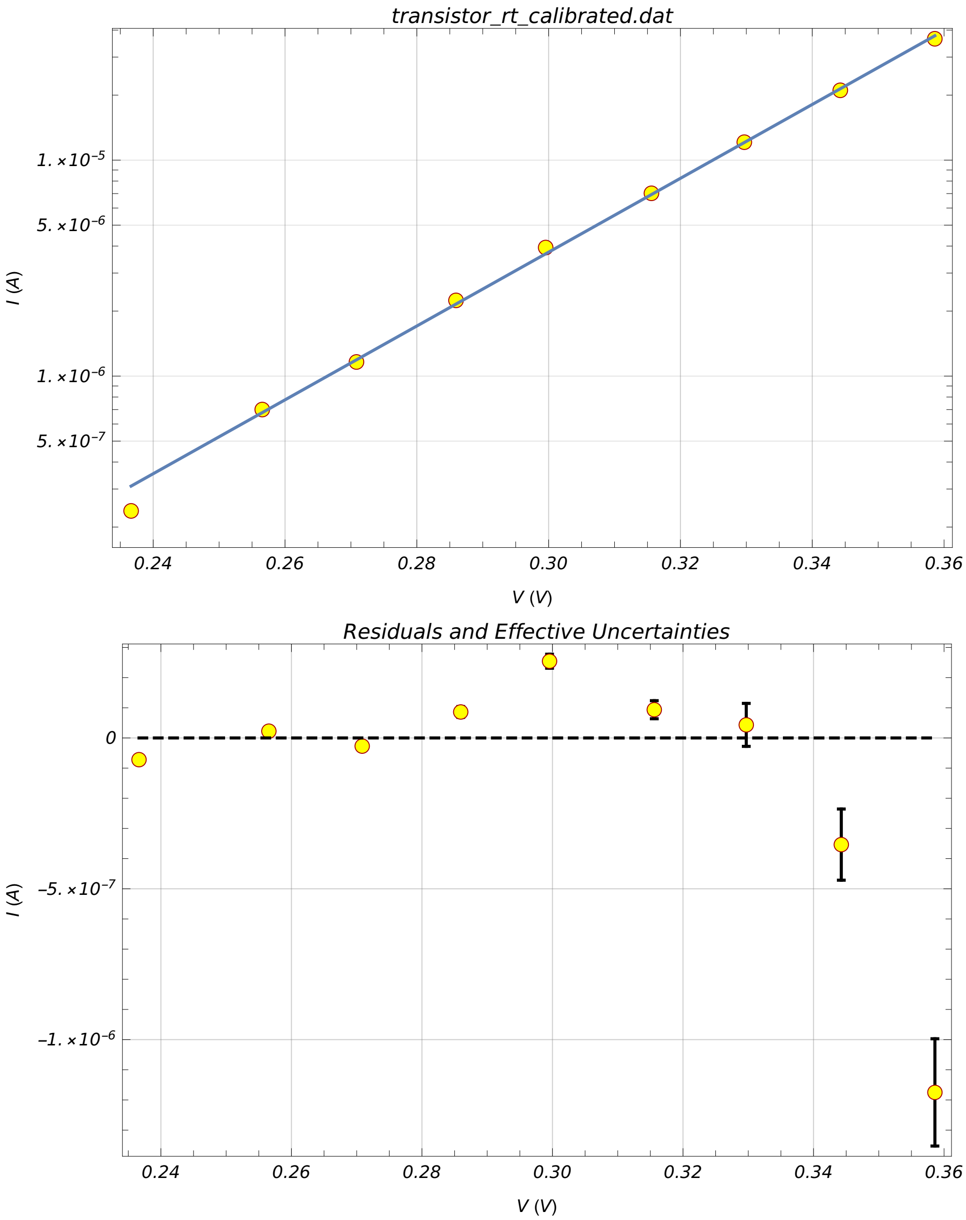
In[295]:=
```
With[{x = SetXRange[ LinearDataPlot[], Log -> False,
    Label -> "Set the X values for the range you wish to keep." ]},
 Print[x];

 XRangeKeep[Sequence @@ x]
]
```

```
{0.22701, 0.3649}

n= 9

27 points removed.
```

In[296]:=
```
DiodeFit[]
```

In[297]:= `LogDifferencePlot[FrameLabel → {"V (V)", "I (A)"}]`

Out[297]=



y(x) = a (Exp[b x] - 1)

a= 2.78634×10^{-11}	b= 39.3656	
σ_a= 6.63776×10^{-13}	σ_b= 0.0734669	$\chi^2/(n-2)$ = 86.5428

In[298]:= `commitFit[{0.22701010416666667`, 0.3649`}, 86.54277146677468`];`

Medium voltage

In[304]:=
```
With[ {name = SystemDialogInput["FileOpen",
    {DataFileName, {"data files" -> {"*.dat", "*.mca"}, "all files" -> {"*"}}}]},
 If[ name =!= $Canceled,
  LoadFile[name]]
]
```

In[305]:=
```
NRangeRemove /@ {1, 1, 17, 17};
```

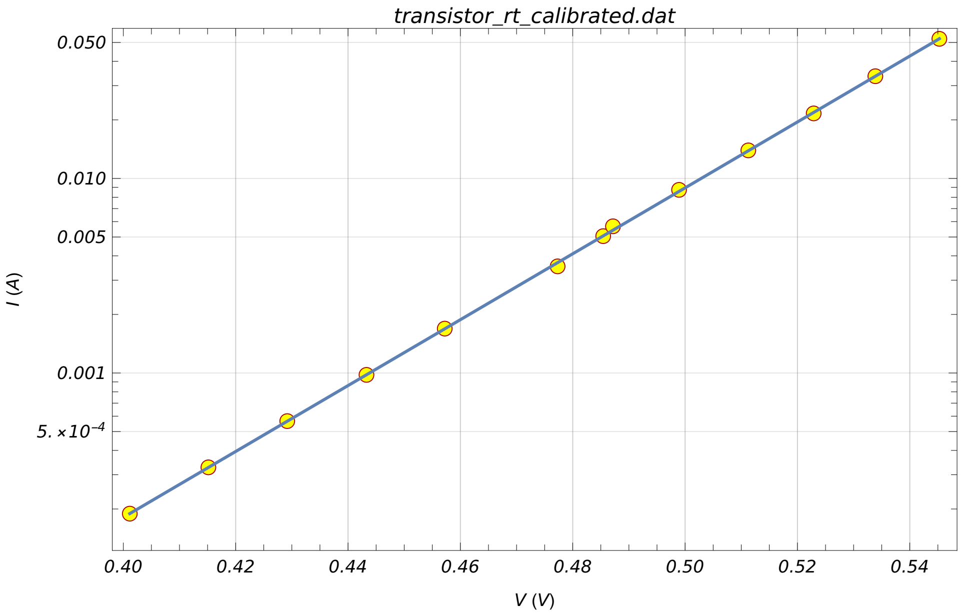
In[306]:=
```
With[{x = SetXRange[ LinearDataPlot[], Log -> False,
    Label -> "Set the X values for the range you wish to keep." ]},
 Print[x];

 XRangeKeep[Sequence @@ x]
]
```

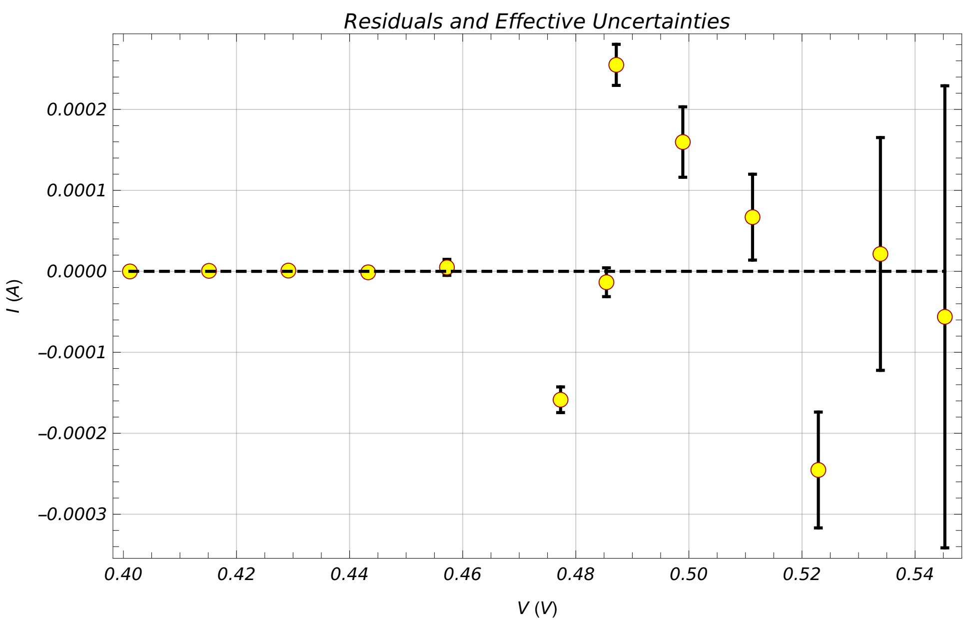
```
{0.3976, 0.5514}

n= 13

23 points removed.
```

In[307]:=
```
DiodeFit[]
```

In[308]:= `LogDifferencePlot[FrameLabel → {"V (V)", "I (A)"}]`

Out[308]=





y(x) = a (Exp[b x] - 1)

a=	b=	
3.04044×10^{-11}	38.9992	
σ_a=	σ_b=	$\chi^2/(n-2)$=
4.3288×10^{-13}	0.0291436	20.852

In[309]:= `commitFit[{0.39760000000000006`, 0.5514000000000001`}, 20.85201748541172`];`

High voltage

In[310]:=
```
With[ {name = SystemDialogInput["FileOpen",
    {DataFileName, {"data files" -> {"*.dat", "*.mca"}, "all files" -> {"*"}}}]},
 If[ name =!= $Canceled,
  LoadFile[name]]
]
```

In[311]:=
```
NRangeRemove /@ {1, 1, 17, 17};
```

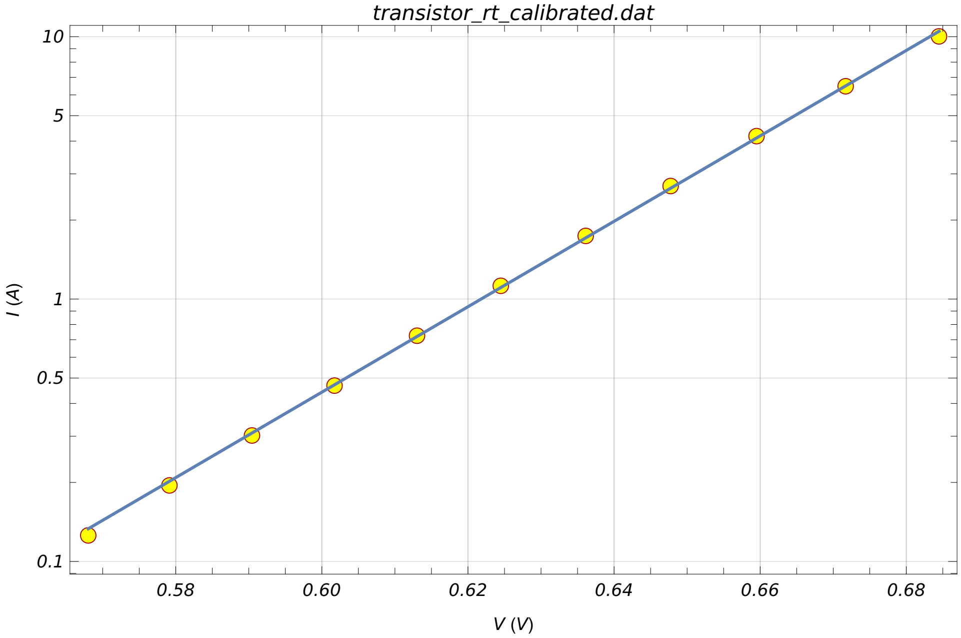
In[312]:=
```
With[{x = SetXRange[ LinearDataPlot[], Log -> False,
    Label -> "Set the X values for the range you wish to keep." ]},
 Print[x];

 XRangeKeep[Sequence @@ x]
]
```

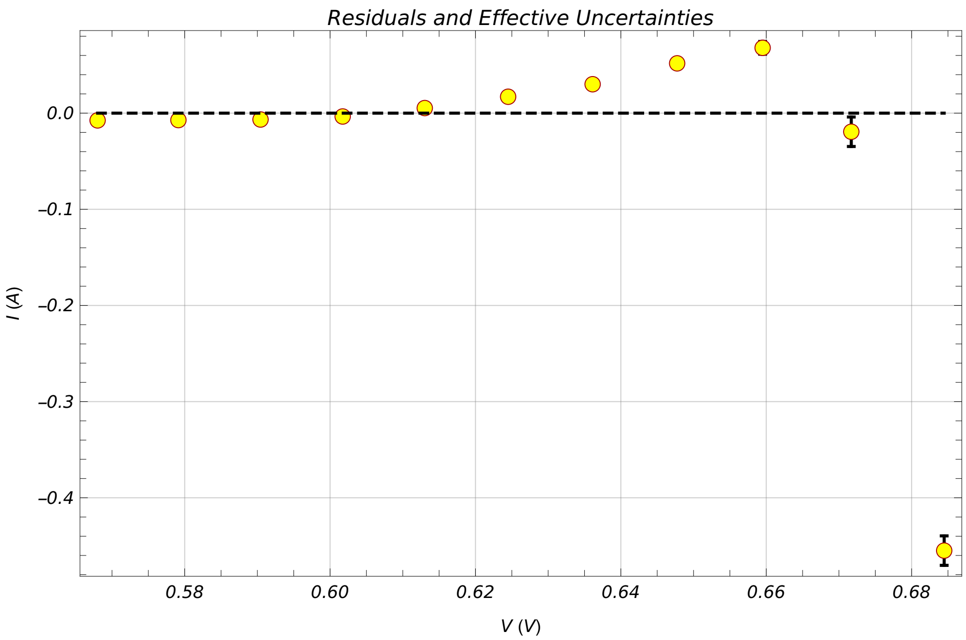
```
{0.5629, 0.693855}

n= 11

25 points removed.
```

In[313]:=
```
DiodeFit[]
```

In[314]:=
```
LogDifferencePlot[FrameLabel → {"V (V)", "I (A)"}]
```

Out[314]=





y(x) = a (Exp[b x] - 1)

a=	b=	
7.5261×10^{-11}	37.4882	
σ_a=	σ_b=	$\chi^2/(n-2)$=
8.96097×10^{-13}	0.0185673	222.001

In[315]:=
```
commitFit[{0.5629000000000001`, 0.6938548958333333`}, 222.0012998180222`];

(* We store the collected data in a separate dataset for silicon
  diode at room temp and re-initialize fitParam for further use. *)
transistorRT = fitParam;
```

```
fitParam = {};
```

Transistor - Dry Ice Temperature

Whole dataset (bad points removed)

In[319]:=
```
With[ {name = SystemDialogInput["FileOpen",
     {DataFileName, {"data files" -> {"*.dat", "*.mca"}, "all files" -> {"*"}}}]},
 If[ name =!= $Canceled,
  LoadFile[name]]
]
```

In[320]:=
```
NRangeRemove /@ {1, 1, 17, 17};
```

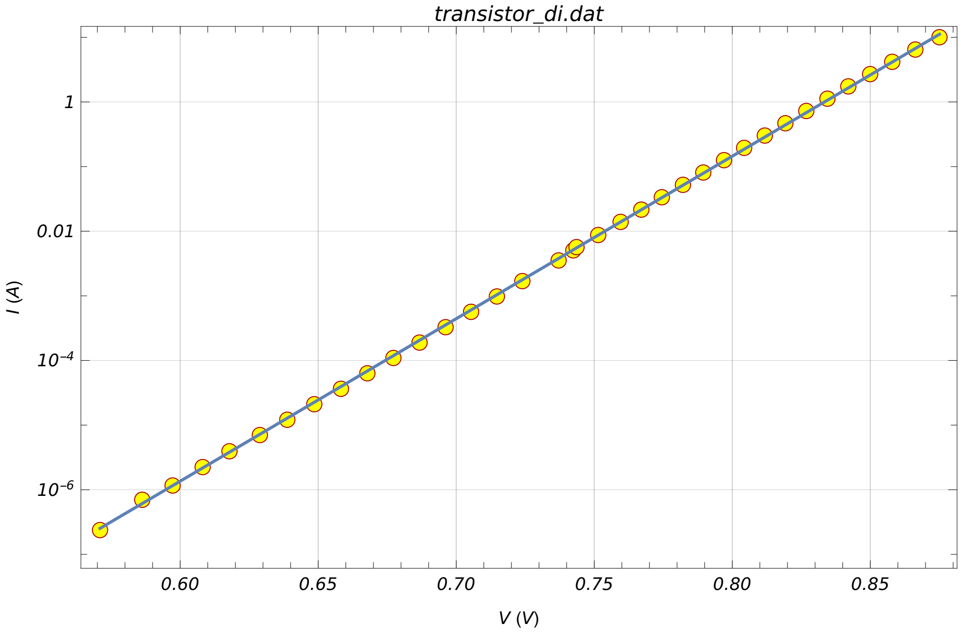
In[321]:=
```
With[{x = SetXRange[ LinearDataPlot[], Log -> False,
     Label -> "Set the X values for the range you wish to keep." ]},
 Print[x];

 XRangeKeep[Sequence @@ x]
]
```

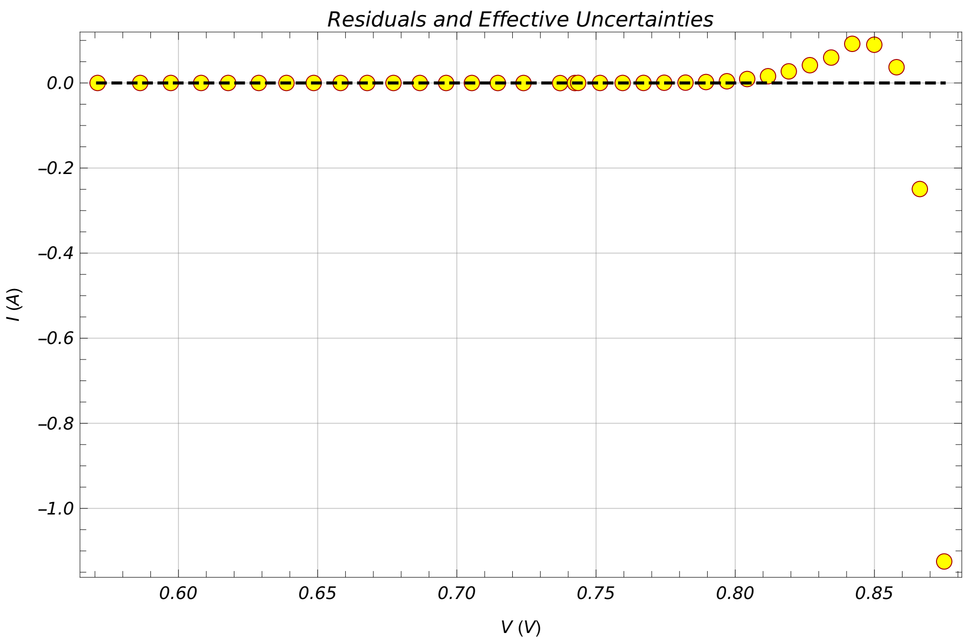
```
{0.564039, 0.881428}

n= 36

0 points removed.
```

In[322]:=
```
DiodeFit[]
```

In[323]:=
```
LogDifferencePlot[FrameLabel → {"V (V)", "I (A)"}]
```

Out[323]=





y(x) = a (Exp[b x] − 1)

a= 1.11695×10^{-21}	b= 57.8879	
σ_a= 7.44262×10^{-24}	σ_b= 0.00787585	$\chi^2/(n-2)$= 578.877

In[324]:=
```
commitFit[{0.5640392291666667`, 0.8814277708333333`}, 578.877313412121`];
```

Low voltage

In[330]:=
```
With[ {name = SystemDialogInput["FileOpen",
    {DataFileName, {"data files" -> {"*.dat", "*.mca"}, "all files" -> {"*"}}}]},
 If[ name =!= $Canceled,
  LoadFile[name]]
]
```

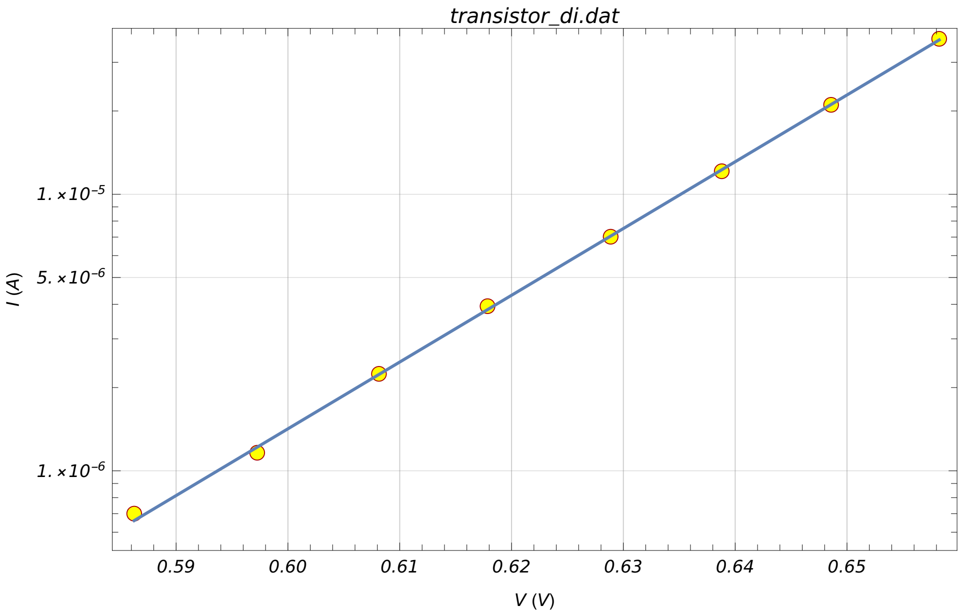
In[331]:=
```
NRangeRemove /@ {1, 1, 17, 17};
```

In[332]:=
```
With[{x = SetXRange[ LinearDataPlot[], Log -> False,
    Label -> "Set the X values for the range you wish to keep." ]},
 Print[x];

 XRangeKeep[Sequence @@ x]
]
```

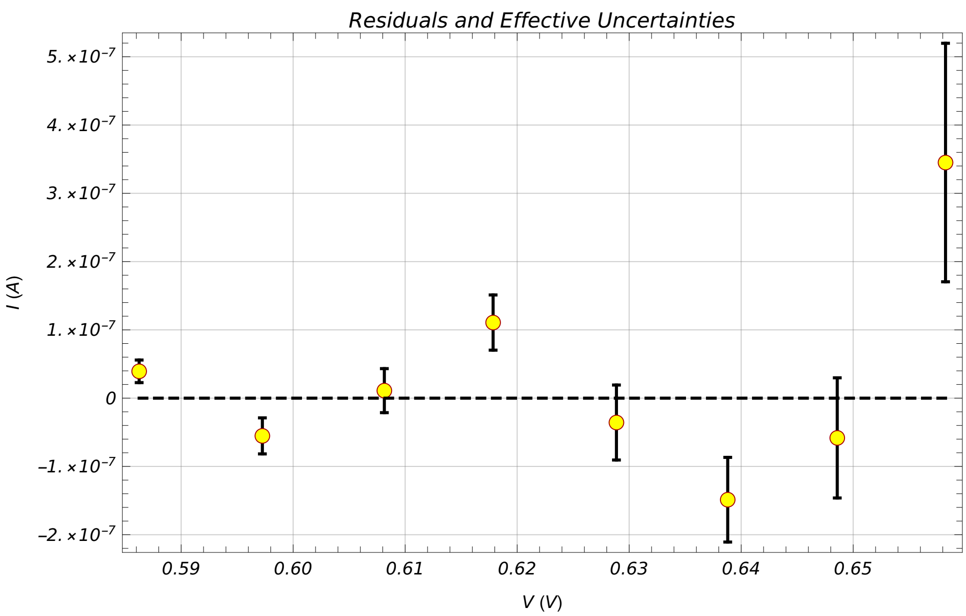
```
{0.5809, 0.6621}
n= 8
28 points removed.
```

In[333]:=
```
DiodeFit[]
```

In[334]:= `LogDifferencePlot[FrameLabel → {"V (V)", "I (A)"}]`



Out[334]=



$y(x) = a\ (\mathrm{Exp}[b\ x] - 1)$

a= 4.67296×10^{-21}	b= 55.578	
σ_a= 5.1192×10^{-22}	σ_b= 0.163026	$\chi^2/(n-2)$ = 4.69663

In[335]:= `commitFit[{0.5809000000000001`, 0.6621`}, 4.696633498979921`];`

Medium voltage

In[340]:=
```
With[ {name = SystemDialogInput["FileOpen",
    {DataFileName, {"data files" -> {"*.dat", "*.mca"}, "all files" -> {"*"}}}]},
 If[ name =!= $Canceled,
  LoadFile[name]]
]
```

In[341]:=
```
NRangeRemove /@ {1, 1, 17, 17};
```

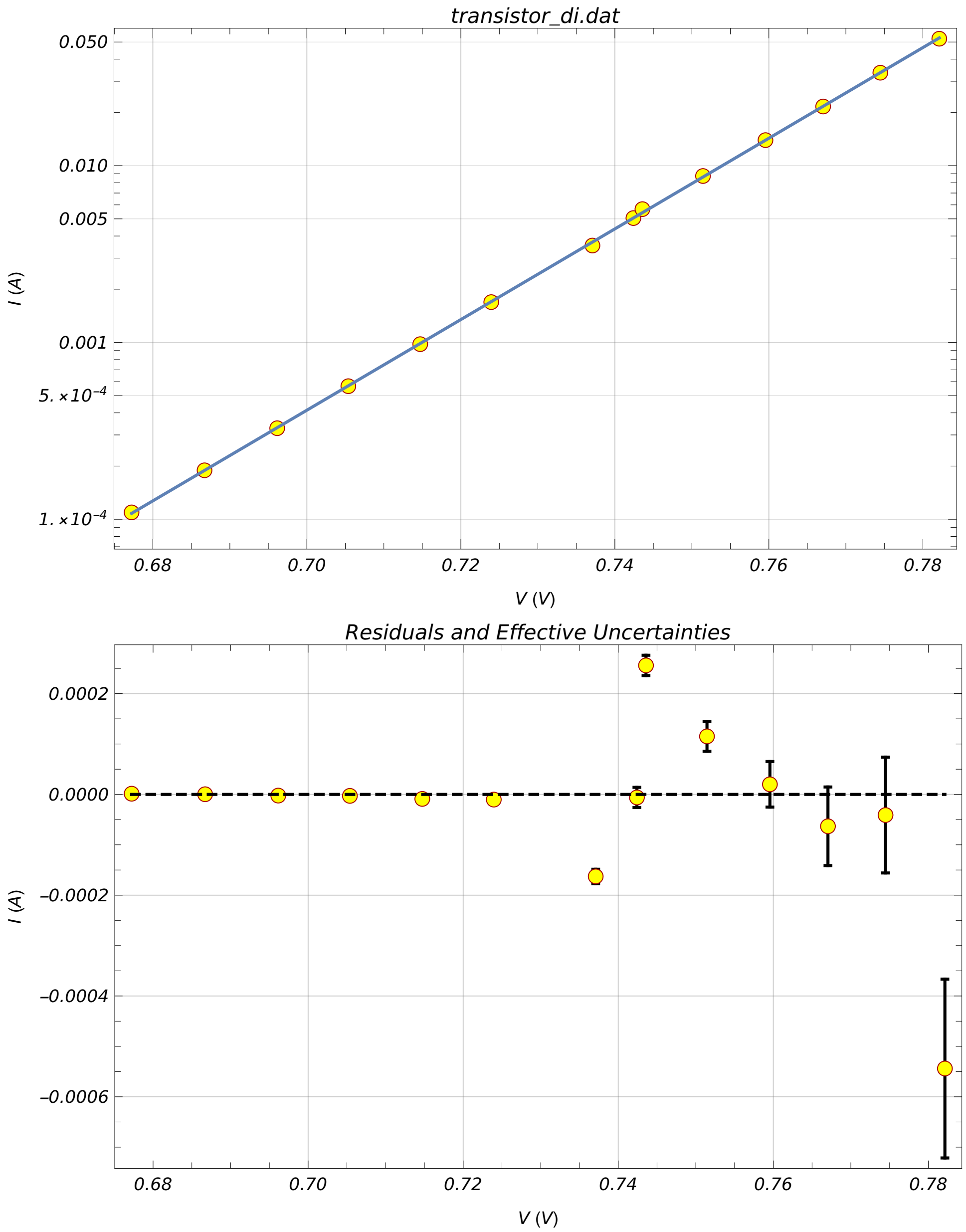
In[342]:=
```
With[{x = SetXRange[ LinearDataPlot[], Log -> False,
    Label -> "Set the X values for the range you wish to keep." ]},
 Print[x];

 XRangeKeep[Sequence @@ x]
]
```

```
{0.6731, 0.786}

n= 14

22 points removed.
```

In[343]:=
```
DiodeFit[]
```

In[344]:=
```
LogDifferencePlot[FrameLabel → {"V (V)", "I (A)"}]
```

Out[344]=



y(x) = a (Exp[b x] − 1)

a= 4.71352×10^{-22}	b= 59.0236	
σ_a= 1.28114×10^{-23}	σ_b= 0.0360829	$\chi^2/(n-2)$= 27.7266

In[345]:=
```
commitFit[{0.6731`, 0.786`}, 27.72657449600054`];
```

High voltage

In[346]:=
```
With[ {name = SystemDialogInput["FileOpen",
    {DataFileName, {"data files" -> {"*.dat", "*.mca"}, "all files" -> {"*"}}}]},
 If[ name =!= $Canceled,
  LoadFile[name]]
]
```

In[347]:=
```
NRangeRemove /@ {1, 1, 17, 17};
```

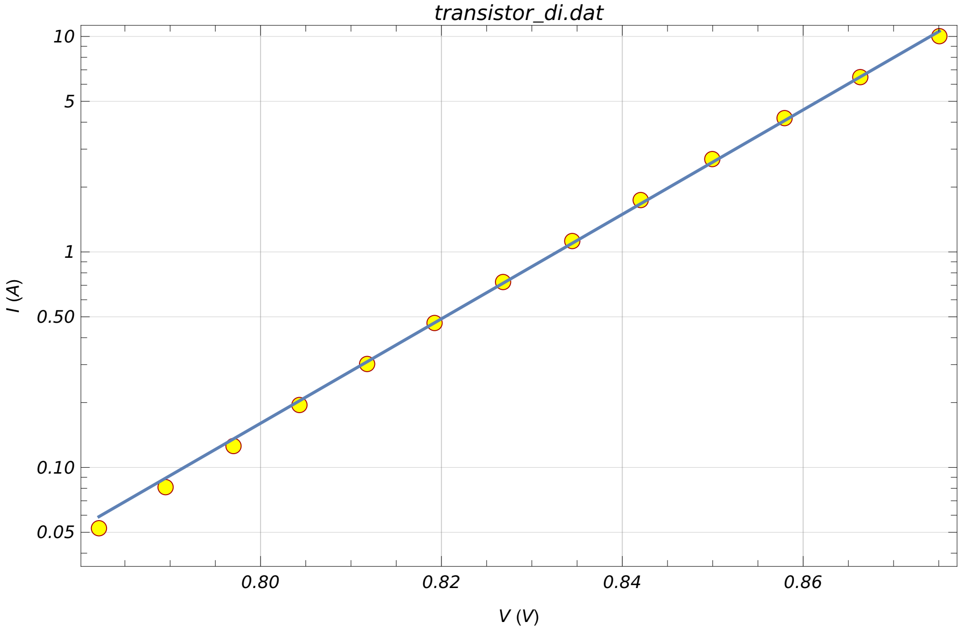
In[348]:=
```
With[{x = SetXRange[ LinearDataPlot[], Log -> False,
    Label -> "Set the X values for the range you wish to keep." ]},
 Print[x];

 XRangeKeep[Sequence @@ x]
]
```

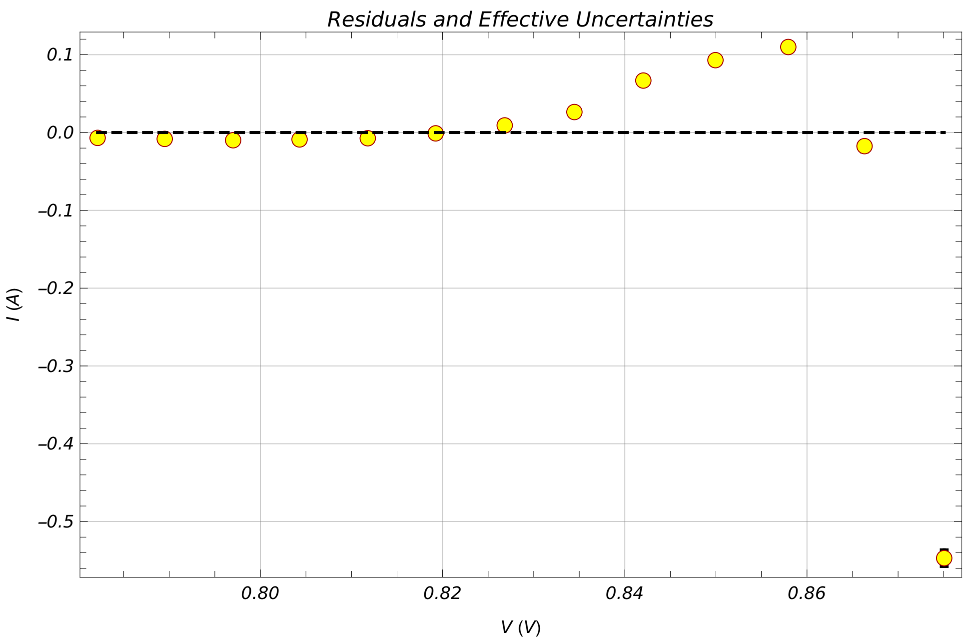
```
{0.7782, 0.881428}

n= 13

23 points removed.
```

In[349]:=
```
DiodeFit[]
```

In[350]:=
```
LogDifferencePlot[FrameLabel → {"V (V)", "I (A)"}]
```

Out[350]=





y(x) = a (Exp[b x] - 1)

a= 6.48147×10^{-21}	b= 55.8177	
σ_a= 4.3966×10^{-23}	σ_b= 0.15547	$\chi^2/(n-2)$ = 702.496

In[351]:=
```
commitFit[{0.7782`, 0.8814277708333333`}, 702.4964280713867`];
```

In[352]:=
```
(* We store the collected data in a separate dataset for silicon
  diode at room temp and re-initialize fitParam for further use. *)
transistorDI = fitParam;
```

In[353]:=
```
fitParam = {};
```

Exporting fit data for safekeeping

In[752]:=
```
paramList = {"siliconRT", "siliconDI",
   "germaniumRT", "germaniumDI", "transistorRT", "transistorDI"};
```

In[753]:=
```
Export[StringJoin[#, ".m"], ToExpression[#]] & /@ paramList;
```

Processing fit parameter data

In[846]:=
```
(* We construct a list of diode parameters (η and I_R)
 from the fit parameter list for each diode configuration. This
 list has structure {region, I_R,sigI_R,η,sigη,χ̃^2}. *)
qe = 1.6021766 * 10^-19 (* C *);
kb = 1.3806485 * 10^-23 (* J K^-1 *);
t = 298 (* K *);
processed[dataset_] := Table[{dataset[[i]][[1]],
    10^-3 dataset[[i]][[2]], 10^-3 dataset[[i]][[3]], qe/(kb t dataset[[i]][[4]]),
    (qe dataset[[i]][[5]])/(kb t (dataset[[i]][[4]])^2), dataset[[i]][[6]]}, {i, 1, Length[dataset]}];
present[dataset_, x_] := Table[{NumberForm[dataset[[i]][[1]], 4],
    NumberForm[10^x dataset[[i]][[2]],
     {8, -RealDigits[10^x dataset[[i]][[3]]][[2]] + 2}], NumberForm[
     10^x dataset[[i]][[3]], {8, -RealDigits[10^x dataset[[i]][[3]]][[2]] + 2}],
    NumberForm[dataset[[i]][[4]], {8, -RealDigits[dataset[[i]][[5]]][[2]] + 2}],
    NumberForm[dataset[[i]][[5]], {8, -RealDigits[dataset[[i]][[5]]][[2]] + 2}],
    Round[dataset[[i]][[6]]]}, {i, 1, Length[dataset]}];
```

In[851]:=
```
ClearAll["siliconRT2", "siliconDI2", "germaniumRT2",
  "germaniumDI2", "transistorRT2", "transistorDI2"];
```

In[852]:=
```
For[i = 1, i ≤ Length[paramList], i++,
  Evaluate[Symbol[StringJoin[paramList[[i]], "2"]]] =
   processed[ToExpression[paramList[[i]]]]];
```

In[866]:=
```
siliconRTpresent =
  Join[{{"Voltage Range (V)", "I_R (μA)", "σ_I_R (nA)", "η", "σ_η", "χ̃^2"}},
   present[siliconRT2, 9]];
```

In[867]:=
```
siliconDIpresent =
  Join[{{"Voltage Range (V)", "I_R (pA)", "σ_I_R (fA)", "η", "σ_η", "χ̃^2"}},
   present[siliconDI2, 15]];
```

In[868]:=
```
germaniumRTpresent =
  Join[{{"Voltage Range (V)", "IR (mA)", "σIR (μA)", "η", "ση", "χ̃2"}},
   present[germaniumRT2, 6]];
```

In[869]:=
```
germaniumDIpresent =
  Join[{{"Voltage Range (V)", "IR (nA)", "σIR (pA)", "η", "ση", "χ̃2"}},
   present[germaniumDI2, 12]];
```

In[870]:=
```
transistorRTpresent =
  Join[{{"Voltage Range (V)", "IR (pA)", "σIR (fA)", "η", "ση", "χ̃2"}},
   present[transistorRT2, 15]];
```

In[871]:=
```
transistorDIpresent =
  Join[{{"Voltage Range (V)", "IR (yA)", "σIR (zA)", "η", "ση", "χ̃2"}},
   present[transistorDI2, 24]];
```

Processed parameter data

In[543]:=
```
grid[data_] := Grid[data, Alignment → Left, Spacings → {2, 1}, Frame → All,
   ItemStyle → "Text", Background → {{Gray, None}, {LightGray, None}}];
```

Silicon Diode - Room temperature

In[872]:=
```
grid[siliconRTpresent]
```

Out[872]=

Voltage Range (V)	I_R (μA)	σ_{I_R} (nA)	η	σ_η	$\tilde{\chi}^2$
{−0.01543, 0.756}	4.3550	0.0047	1.95420	0.00018	513
{−0.01543, 0.1484}	3.560	0.022	1.8069	0.0046	170
{0.206, 0.5024}	3.999	0.015	1.93658	0.00098	41
{0.501, 0.756}	6.564	0.029	2.01676	0.00071	626

Silicon Diode - Dry ice temperature

In[873]:=
```
grid[siliconDIpresent]
```

Out[873]=

Voltage Range (V)	I_R (pA)	σ_{I_R} (fA)	η	σ_η	$\tilde{\chi}^2$
{0.3231, 0.9117}	14.030	0.036	1.27954	0.00014	453
{0.3231, 0.5102}	5.304	0.089	1.1961	0.0014	93
{0.5082, 0.7202}	21.94	0.22	1.30992	0.00070	22
{0.7176, 0.9119}	11.92	0.12	1.27156	0.00051	785

Germanium Diode - Room temperature

In[874]:=
```
grid[germaniumRTpresent]
```

Out[874]=

Voltage Range (V)	I_R (mA)	σ_{I_R} (μA)	η	σ_η	$\tilde{\chi}^2$
{−0.008776, 0.4179}	4.0369	0.0058	1.98973	0.00045	10 171
{−0.008776, 0.0908}	0.7776	0.0072	1.2841	0.0053	16
{0.104, 0.2466}	1.8845	0.0075	1.6624	0.0015	412
{0.2473, 0.4179}	9.782	0.021	2.28325	0.00080	4169

Germanium Diode - Dry ice temperature

In[875]:=
```
grid[germaniumDIpresent]
```

Out[875]=

Voltage Range (V)	I_R (nA)	σ_{I_R} (pA)	η	σ_η	$\tilde{\chi}^2$
{0.0528, 0.5649}	475.9	1.2	1.23581	0.00022	43 187
{0.0528, 0.1999}	20.85	0.50	0.9420	0.0032	5
{0.2008, 0.3901}	66.20	0.36	1.06489	0.00048	140
{0.4148, 0.5649}	10850.	30.	1.55183	0.00035	45 694

Transistor - Room temperature

In[877]:=
```
grid[transistorRTpresent]
```

Out[877]=

Voltage Range (V)	I_R (pA)	σ_{I_R} (fA)	η	σ_η	$\tilde{\chi}^2$
{0.227, 0.6939}	36.42	0.12	1.00817	0.00014	205
{0.227, 0.3649}	27.86	0.66	0.9892	0.0018	87
{0.3976, 0.5514}	30.40	0.43	0.99852	0.00075	21
{0.5629, 0.6939}	75.26	0.90	1.03876	0.00051	222

Transistor - Dry ice temperature

In[878]:=
```
grid[transistorDIpresent]
```

Out[878]=

Voltage Range (V)	I_R (yA)	σ_{I_R} (zA)	η	σ_η	$\tilde{\chi}^2$
{0.564, 0.8814}	1.1170	0.0074	0.672703	0.000092	579
{0.5809, 0.6621}	4.67	0.51	0.7007	0.0021	5
{0.6731, 0.786}	0.471	0.013	0.65976	0.00040	28
{0.7782, 0.8814}	6.481	0.044	0.6977	0.0019	702

Analysis of the PN junction theory

Fit residuals

We observe that our fits share the same structure in the fit residuals, indicating that the PN junction theory presented does not completely explain the I-V behavior of PN-junction diodes. This structure is easy to observe in the plots above: residuals start out small, then increase in the positive direction (positive residuals increasing in magnitude), then decrease in magnitude, cross the zero-residual line, and dramatically increase in the negative direction (negative residuals increasing in magnitude). This indicates either that our theory must contain a correction term we have not accounted for, and/or our assumption that the ideality coefficient η is a constant over a given I-V curve in fact does not adequately hold over our measured regions.

Residuals over different regions

Following the observations above, we attempted several fits for each dataset - for each diode at both temperature (room temperature and dry ice temperature), we perform a fit over low-current, medium-current, and high-current regions. From the fit parameters, we can obtain I_R and η, the results of which are shown in the tables above for all diodes, temperatures, and current regions, along with the corresponding $\tilde{\chi}^2$ of the fit.

We observe that the residuals maintain the general structure described above over all fitted regions. Furthermore, we observe a significant variation in goodness-of-fit ($\tilde{\chi}^2$) over different regions of the same IV-curve. This indicates that there must be a correction term to our model, and that this correction term cannot present itself *only* as a variation in η across the IV-curve (if it were only a variation in η, we would expect the goodness-of-fit of our data to the model to always improve when we fit over smaller subsections of our data, and this is not consistently observed in the tables above for the high-current fits, indicating the presence of a correction term not in η that becomes significant at high currents). However, the significant differences in $\hat{\chi}^2$ and in our best estimates for η using the fits over subsections of each IV-curve indicate that the correction term does include a variation of η over the IV-curve.

Observations from fits

The different diodes differ in their behavior over different current and temperature ranges. The best fits are obtained using the germanium diode and the transistor at dry ice temperatures, over the low current range. The germanium diode at dry ice temperature seems to fit the model relatively well when fit over subsections of the IV-curve, but has a much worse fit over the entire dataset. This indicates that η is not approximately constant as assumed for this configuration, and that the correction term to the model is dominated by the variation of η across the IV-curve for this configuration. The transistor at dry ice temperature has the same issue, but much less severe. It is therefore the dataset that fits the model the most closely. The transistor at room temperature fits the model best over the whole dataset, but it is not a very good fit $\left(\tilde{\chi}^2 = 205\right)$.

With the exception of the silicon diode at both temperatures and the transistor at room temperature, we observe that the data fits the model best at low-current, worsening as current increases. This general trend may be caused by series resistance becoming apparent at high-currents.

Series resistance

At large currents, we expect a voltage drop to occur due to the resistance between each of the diode's connecting leads. This causes a current-dependent decrease in the voltage across the diode, such that at high currents the IV-curve for the diode diverges from and lies below the IV-curve predicted by the theory, with divergence from the theory increasing with current. Now, recall that the diode equation predicts current across the diode to vary exponentially with the inverse of temperature, T. Therefore, assuming resistance changes only slowly with temperature, we expect larger currents at lower temperatures for a given voltage to result in series resistance to have a greater effect on the cold data than on the room temperature data.

Below is an interactive plot where we can observe the effects of series resistance on the IV-curves predicted by the theory, for a diode with $I_R = 10^{-9}\,A$ and $\eta = 1$. We obtain the plot by numerically solving the implicit equation resulting from applying Kirchoff's Voltage Law to a voltage drop across a diode in series with a resistor, whose resistance can be varied to observe the effects on the IV-curves.

In[884]:=
```
ClearAll[t, i]
```

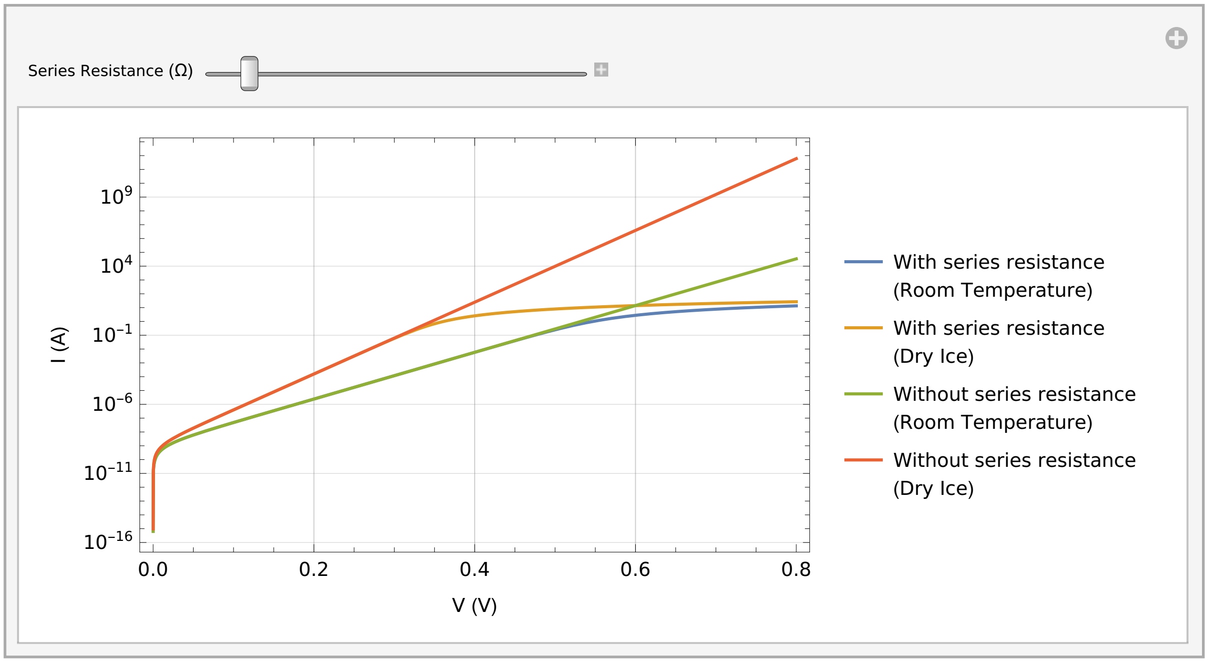
In[885]:=
```
iR = 10^-9;
eta = 1;
```

In[887]:=
```
i[ir_, η_, v_, t_] := ir (ⅇ^((qe v)/(η kb t)) - 1);
```

In[888]:=
```
iRes[ir_, η_, v_, t_, r_] := i[ir, η, vDiode, t] /.
    FindRoot[v == i[ir, η, vDiode, t] r + vDiode, {vDiode, v}][[1]] // Quiet
```

In[955]:=
```
Manipulate[LogPlot[{iRes[iR, eta, v, 298, r],
    iRes[iR, eta, v, 194, r], i[iR, eta, v, 298], i[iR, eta, v, 194]}, {v, 0, 0.8},
  FrameLabel → {"V (V)", "I (A)"}, PlotLegends → {"With series resistance
(Room Temperature)", "With series resistance
(Dry Ice)", "Without series resistance
(Room Temperature)", "Without series resistance
(Dry Ice)"}, PlotRange → All, ImageSize → 400,
  LabelStyle → {FontSize → 10}], {{r, 0, "Series Resistance (Ω)"}, 0, 0.2}]
```

Out[955]=



Indeed, in the plot above, we can observe a series resistance effect with the characteristics proposed above at high currents, with a greater effect on the cold IV-curve than on the room temperature IV-curve (the onset of significant divergence from the diode equation occurs at lower voltages in the cold IV-curve).

Now, observe that the data from the fits presented above shows significantly worse fits for high-current data, with the high-current fits worsening at dry-ice temperature. From the above, this is exactly what we would expect of data containing evidence of series resistance being fit against the diode equation. This indicates that the correction terms to our diode equation must account for series resistance, and as stated before, variability of η across the IV-curve.

Determining E_g

Solving equation (13.2) from the lab manual for two different temperatures T_1, T_2, we obtain an expression of for E_g in units of eV:

$E_g = \frac{k_B}{q_e} \frac{(\eta_1\,\eta_2)\,(T_1\,T_2)}{(T_2\,\eta_2 - T_1\,\eta_1)}\,\mathrm{Log}\left[\frac{I_{R_1}}{I_{R_2}}\right].$

In[790]:=
```
<< SimpleErrorPropagation`
```

In[791]:=
```
? PropagateUncertainties
```

PropagateUncertainties[func, vars] propagates uncertainties in variables listed
in vars = {variable1, variable2,...} and retuns the propagated uncertainty in func.
func must necessarily be differentiable with respect to all variables in vars,
and the uncertainties in variables in vars must be independent.

It will return an algebraic expression in terms of the variables
in vars, with uncertainty in some variable denoted by sigmaVariable.
It can be used either by providing an algebraic expression, then substituting values for the
variables and uncertainties in a subsequent operation, or simply by assigning values
and uncertainties to each variable using the naming conventions mentioned. In the
latter case, it will be necessary to localize the variables in vars using Module or Block.

Note: Loading SimpleErrorPropagation` clears any variables named 'variance', 'varianceList'
or 'PropagateUncertainties' due to function and subfunction names in the Package.

In[792]:=

$$\mathtt{eg[t1\_, t2\_, ir1\_, ir2\_, eta1\_, eta2\_]} := \frac{\mathtt{kb}}{\mathtt{qe}}\,\frac{(\mathtt{eta1\ eta2})\ (\mathtt{t1\ t2})}{(\mathtt{t2\ eta2 - t1\ eta1})}\,\mathtt{Log}\left[\frac{\mathtt{ir2}}{\mathtt{ir1}}\right];$$

In[794]:=
```
PropagateUncertainties[
  eg[t1, t2, ir1, ir2, eta1, eta2], {eta1, eta2, ir1, ir2}] // Simplify
```

Out[794]=

$$\sqrt{\left(\frac{1}{\mathtt{ir1}^2\,\mathtt{ir2}^2\,(\mathtt{eta1\,t1} - 1.\,\mathtt{eta2\,t2})^4}\mathtt{t1}^2\,\mathtt{t2}^2\left(\mathtt{eta1}^2\,\mathtt{eta2}^2\left(\mathtt{eta1}^2\left(7.42584\times10^{-9}\,\mathtt{ir2}^2\,\mathtt{sigmaIr1}^2 + 7.42584\times10^{-9}\,\mathtt{ir1}^2\,\mathtt{sigmaIr2}^2\right)\mathtt{t1}^2 + \mathtt{eta1\,eta2}\left(-1.48517\times10^{-8}\,\mathtt{ir2}^2\,\mathtt{sigmaIr1}^2 - 1.48517\times10^{-8}\,\mathtt{ir1}^2\,\mathtt{sigmaIr2}^2\right)\mathtt{t1\,t2} + \mathtt{eta2}^2\left(7.42584\times10^{-9}\,\mathtt{ir2}^2\,\mathtt{sigmaIr1}^2 + 7.42584\times10^{-9}\,\mathtt{ir1}^2\,\mathtt{sigmaIr2}^2\right)\mathtt{t2}^2\right) + \mathtt{ir1}^2\,\mathtt{ir2}^2\left(7.42584\times10^{-9}\,\mathtt{eta1}^4\,\mathtt{sigmaEta2}^2\,\mathtt{t1}^2 + 7.42584\times10^{-9}\,\mathtt{eta2}^4\,\mathtt{sigmaEta1}^2\,\mathtt{t2}^2\right)\mathtt{Log}\left[\frac{\mathtt{ir2}}{\mathtt{ir1}}\right]^2\right)\right)}$$

In[795]:=
```
egUnc[t1_, t2_, ir1_, sigmaIr1_, ir2_,
    sigmaIr2_, eta1_, sigmaEta1_, eta2_, sigmaEta2_] :=
   {eg[t1, t2, ir1, ir2, eta1, eta2], Sqrt[(1/(ir1^2 ir2^2 (eta1 t1 - 1.` eta2 t2)^4)
        t1^2 t2^2 (eta1^2 eta2^2 (eta1^2 (7.425838191741328`*^-9 ir2^2 sigmaIr1^2 +
                7.425838191741328`*^-9 ir1^2 sigmaIr2^2) t1^2 + eta1 eta2
              (-1.4851676383482656`*^-8 ir2^2 sigmaIr1^2 - 1.4851676383482656`*^-8
                ir1^2 sigmaIr2^2) t1 t2 + eta2^2 (7.425838191741328`*^-9 ir2^2 sigmaIr1^2 +
                7.425838191741328`*^-9 ir1^2 sigmaIr2^2) t2^2) +
          ir1^2 ir2^2 (7.425838191741328`*^-9 eta1^4 sigmaEta2^2 t1^2 +
              7.425838191741328`*^-9 eta2^4 sigmaEta1^2 t2^2) Log[ir2/ir1]^2))};
```

In[798]:=
```
diodeList = {"siliconRT2", "siliconDI2",
    "germaniumRT2", "germaniumDI2", "transistorRT2", "transistorDI2"};
```

In[809]:=
```
(* List of best fit estimates of diode parameters,
ordered as given by diodeList above. *)
```

In[879]:=
```
bestFits = Flatten[
    Table[
     Select[
      Evaluate[
       Symbol[
        diodeList[[i]]]],
      #[[6]] == Min[
          Evaluate[
            Symbol[
             diodeList[[i]]]][[All, 6]]]
        &],
     {i, 1, Length[diodeList]}], 1
   ];
```

In[921]:=
```
egPresent = {{}, {}, {}};
egPresent[[1]] = Join[{"Silicon Diode"}, egList[[1]]];
egPresent[[2]] = Join[{"Germanium Diode"}, egList[[2]]];
egPresent[[3]] = Join[{"Transistor"}, egList[[3]]];
```

In[933]:=
```
grid[egPresent]
```

Out[933]=

Diode Type	E_g(eV)	σ_{E_g}(eV)
Silicon Diode	0.47692	0.00065
Germanium Diode	0.3194	0.0025
Transistor	0.4904	0.0036

We observe large discrepancies between our estimates above and the known semiconductor gap energies of 1.12 eV for silicon and 0.67 eV for germanium. This could be due to a variety of factors, including the stated variability of η across the IV-curve which we have neglected in our analysis, imperfections in the PN-junctions of our diode, ohmic heating in the diode, undetected systematic errors in the apparatus, or human error during calibration.

Limitations of diode equation

The idealized one-dimensional model of the diode neglects effects such as internal resistance of the diode, capacitance between the two sides of the depletion layer, band gap shift due to doping.