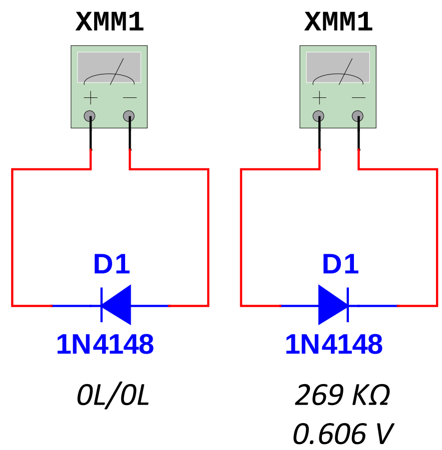
BEE 332 Devices and circuits II
Spring 2017
Lab 1: Bipolar junction transistor characterization instructor's notes*

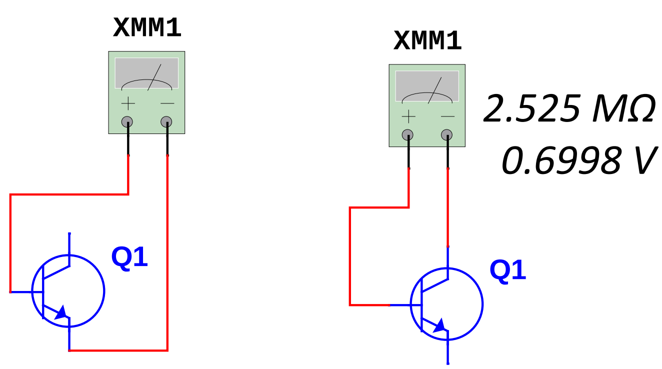
2.3 Diode measurement

My results, likely typical.



2.4 Identify the base

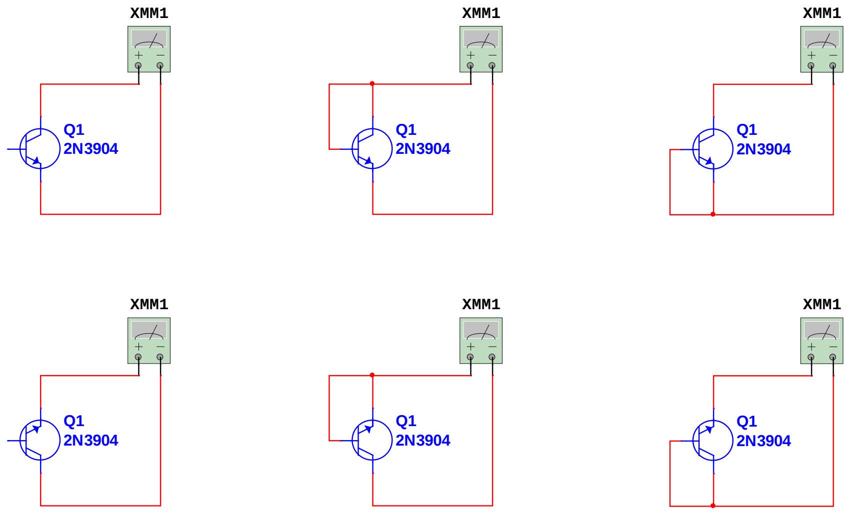
When the positive lead of the multimeter is connected to the middle lead, there is a diode drop to either of the other leads. All other combinations are open. Shown here are my results, likely typical. This indicates the middle lead is the base and that the transistor is an NPN.



* These notes were written by Nicole Hamilton.

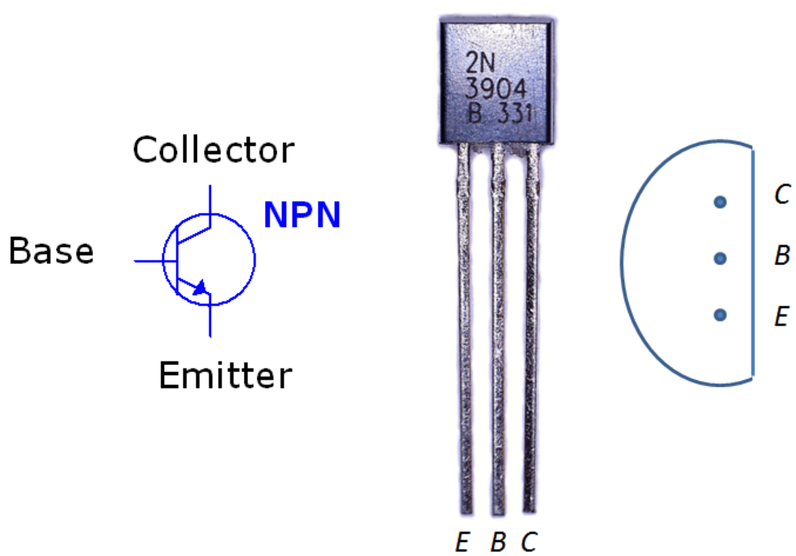
2.5 Identify the collector and emitter

My results, likely typical.



2.6 Questions

1. Picture of the transistor with leads identified. I will accept either a labeled photo or drawing of the package or a component-side view.

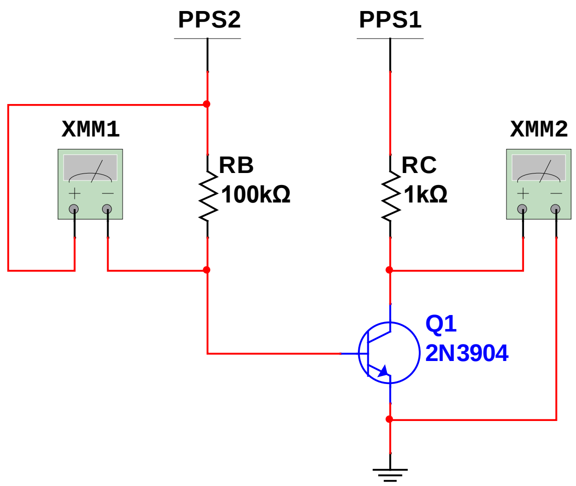


2. Is it possible to distinguish the emitter from the collector using only a multimeter? Yes, but only barely. (I will accept if you said no.) The base-collector junction has a slightly lower resistance.

3. Yes, this matches the datasheet. (Surprise.)
4. With the base lead open-circuited, the BJT is normally-off. The B-E junction must be forward-biased for conduction to occur.

3.2 Measurements

For this circuit, here were my measurements, likely typical.



Measured values (Ω)

RB	99,080
RC	982

PPS2 = 1.0 V

PPS1	VRB	VCE	IB (μA)	IC (mA)	IC / IB
0	0.470	0.005	4.744	-0.005	-1.013
1	0.360	0.159	3.633	0.857	235.817
2	0.352	0.851	3.553	1.170	329.432
3	0.353	1.840	3.563	1.181	331.557
4	0.354	2.830	3.573	1.191	333.470
5	0.354	3.821	3.573	1.201	336.035
6	0.354	4.811	3.573	1.211	338.886
7	0.355	5.801	3.583	1.221	340.773
8	0.356	6.793	3.593	1.229	342.083
9	0.357	7.784	3.603	1.238	343.669
10	0.357	8.774	3.603	1.248	346.495
Interpolated at VCE = 3.0 V					
4.172	0.354	3.000	3.573	1.193	333.910

PPS2 = 1.25 V

PPS1	VRB	VCE	IB (μA)	IC (mA)	IC / IB
0	0.713	0.006	7.196	-0.006	-0.849
1	0.610	0.127	6.157	0.889	144.409
2	0.590	0.211	5.955	1.822	306.003
3	0.588	1.072	5.935	1.963	330.829
4	0.589	2.052	5.945	1.984	333.694
5	0.590	3.035	5.955	2.001	336.035
6	0.591	4.013	5.965	2.023	339.223
7	0.592	4.996	5.975	2.041	341.547
8	0.593	5.982	5.985	2.055	343.353
9	0.594	6.965	5.995	2.072	345.663
10	0.595	7.947	6.005	2.091	348.134

Interpolated at VCE = 3.0 V

4.964	0.590	3.000	5.954	2.000	335.952

PPS2 = 1.5 V

PPS1	VRB	VCE	IB (μA)	IC (mA)	IC / IB
0	0.955	0.006	9.639	-0.007	-0.678
1	0.860	0.113	8.680	0.903	104.080
2	0.839	0.156	8.468	1.877	221.702
3	0.828	0.326	8.357	2.723	325.829
4	0.828	1.285	8.357	2.765	330.837
5	0.829	2.256	8.367	2.794	333.967
6	0.830	3.225	8.377	2.826	337.333
7	0.830	4.172	8.377	2.880	343.776
8	0.835	5.148	8.428	2.904	344.618
9	0.836	6.128	8.438	2.925	346.619
10	0.837	7.100	8.448	2.953	349.580

Interpolated at VCE = 3.0 V

5.768	0.830	3.000	8.375	2.819	336.552

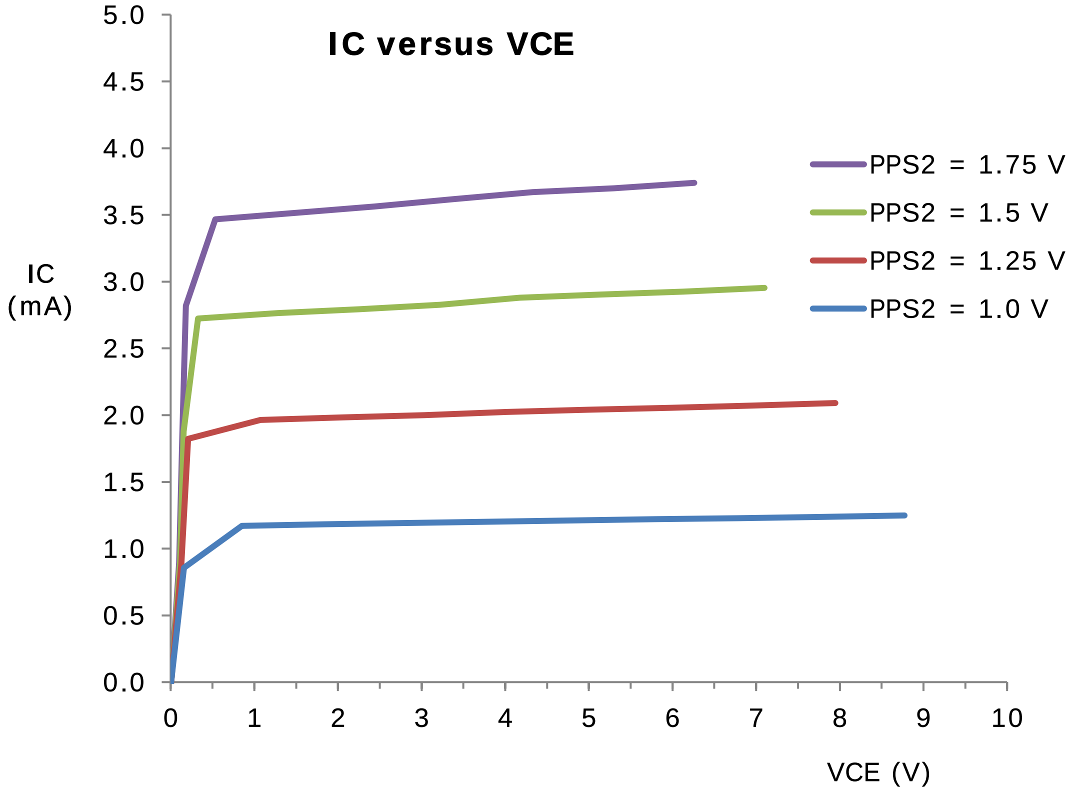
PPS2 = 1.75 V

PPS1	VRB	VCE	IB (μA)	IC (mA)	IC / IB
0	1.192	0.007	11.920	-0.007	-0.549
1	1.107	0.103	11.070	0.897	80.993
2	1.087	0.139	10.870	1.861	171.196
3	1.075	0.181	10.750	2.819	262.268
4	1.070	0.533	10.700	3.467	324.019
5	1.071	1.485	10.710	3.515	328.198
6	1.073	2.437	10.730	3.563	332.060
7	1.075	3.382	10.750	3.618	336.558

8	1.078	4.330	10.780	3.670	340.445
9	1.080	5.300	10.800	3.700	342.593
10	1.082	6.260	10.820	3.740	345.656
Interpolated at VCE = 3.0 V					
6.596	1.074	3.000	10.742	3.596	334.740

3.3 Analysis

1. Graph of individual curves of IC versus VCE. In the forward active region, IC is almost flat with VCE.

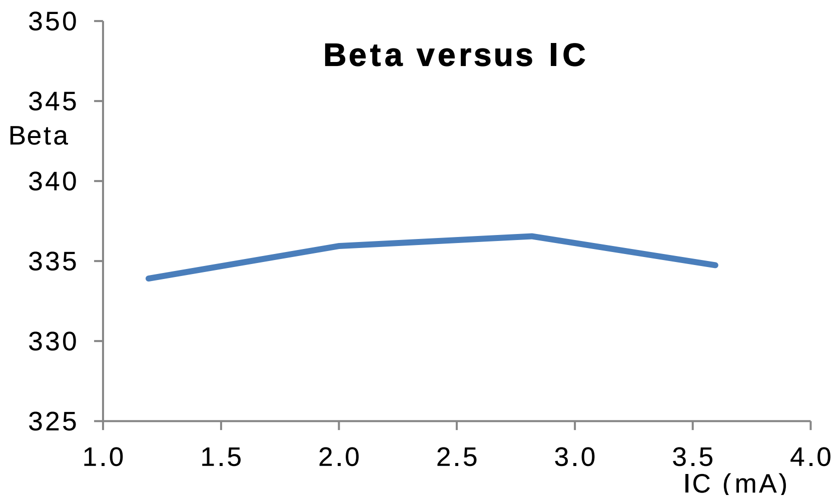


2. Use interpolation to find estimated values of PPS1, VRB, IB, IC and βF corresponding to VCE = 3.0 V.

   As shown above.

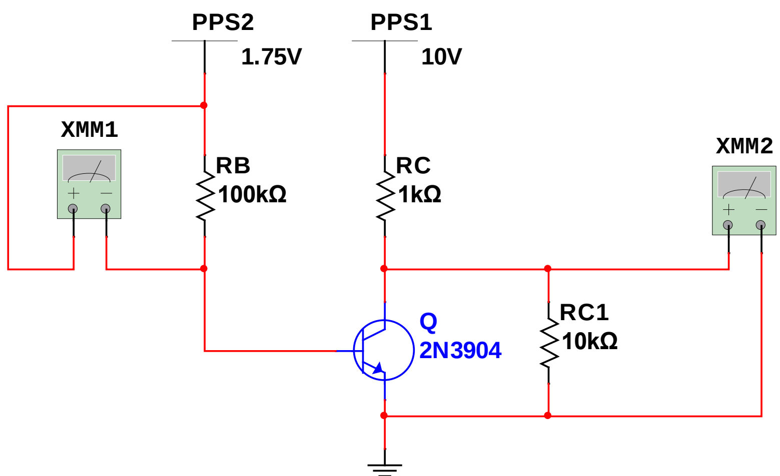
3. Plot βF versus IC at VCE = 3.0 V. Comment on the dependence of βF on IC and estimate the value of IC which yields the maximum βF.

   Here were my results, likely roughly typical. In my tests, βF was reasonably flat with a peak at roughly IC = 2.75 mA. YMMV.



4.2 Measurements

For this circuit, here were my measurements, likely typical.



Measured values (Ω)

RB	99,080
RC	982
RC1	9,724

PPS2 = 1.0 V

PPS1	VRB	VCE	IB (μA)	IC (mA)	IC / IB
0	0.470	0.004	4.744	-0.004	-0.943
1	0.359	0.157	3.623	0.859	236.971
2	0.348	0.752	3.512	1.271	361.834
3	0.349	1.649	3.522	1.376	390.575
4	0.349	2.547	3.522	1.480	420.063
5	0.349	3.446	3.522	1.582	449.262
6	0.350	4.345	3.532	1.685	477.095
7	0.350	5.245	3.532	1.787	505.922
8	0.351	6.143	3.543	1.891	533.801
9	0.351	7.044	3.543	1.992	562.259
10	0.352	7.942	3.553	2.096	589.898
Interpolated at VCE = 3.0 V					
4.504	0.349	3.000	3.522	1.531	434.777

PPS2 = 1.25 V

PPS1	VRB	VCE	IB (μA)	IC (mA)	IC / IB
0	0.710	0.005	7.166	-0.006	-0.776
1	0.607	0.127	6.126	0.889	145.078
2	0.584	0.206	5.894	1.827	309.967
3	0.582	0.952	5.874	2.085	355.009
4	0.582	1.842	5.874	2.198	374.113
5	0.582	2.734	5.874	2.308	392.836
6	0.583	3.624	5.884	2.420	411.199
7	0.584	4.516	5.894	2.530	429.154
8	0.584	5.407	5.894	2.641	447.986
9	0.585	6.300	5.904	2.749	465.674
10	0.586	7.188	5.914	2.864	484.164
Interpolated at VCE = 3.0 V					
5.299	0.582	3.000	5.877	2.341	398.324

PPS2 = 1.5 V

PPS1	VRB	VCE	IB (μA)	IC (mA)	IC / IB
0	0.955	0.006	9.639	-0.006	-0.655
1	0.858	0.112	8.660	0.904	104.369
2	0.834	0.156	8.417	1.878	223.052
3	0.820	0.256	8.276	2.794	337.608
4	0.819	1.076	8.266	2.978	360.220
5	0.819	1.956	8.266	3.100	375.003
6	0.820	2.840	8.276	3.218	388.819
7	0.821	3.730	8.286	3.330	401.864

8	0.822	4.613	8.296	3.449	415.736
9	0.823	5.497	8.306	3.567	429.452
10	0.824	6.377	8.317	3.689	443.625

Interpolated at VCE = 3.0 V

6.180	0.820	3.000	8.278	3.238	391.164

PPS2 = 1.75 V

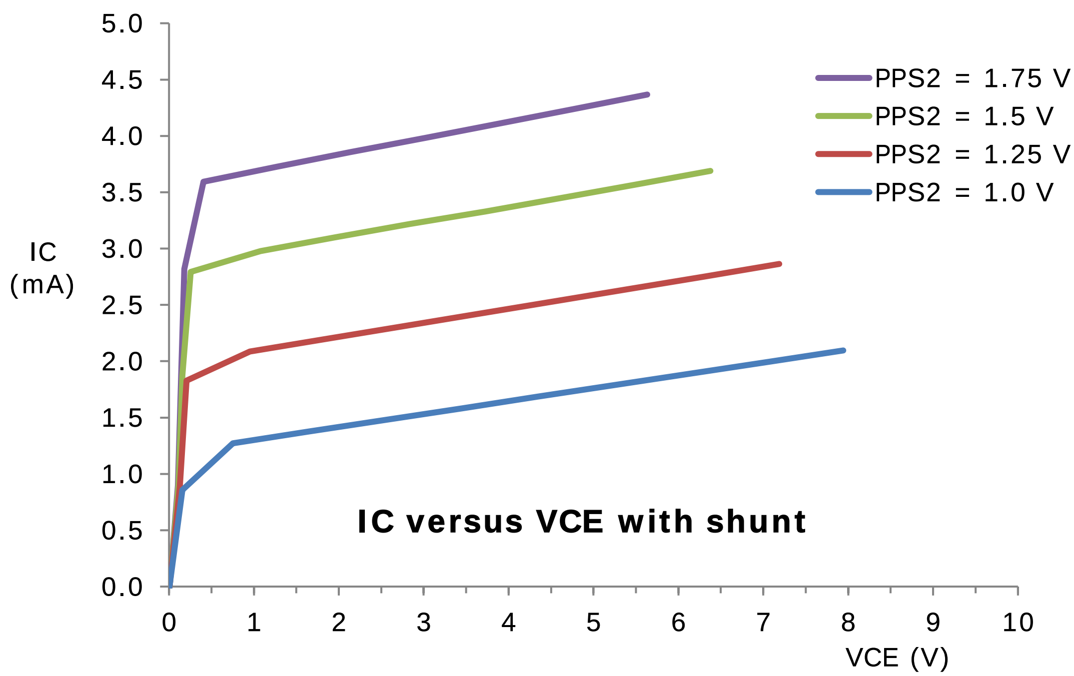
PPS1	VRB	VCE	IB (μA)	IC (mA)	IC / IB
0	1.198	0.007	11.980	-0.007	-0.553
1	1.109	0.104	11.090	0.896	80.789
2	1.084	0.141	10.840	1.859	171.481
3	1.068	0.182	10.680	2.818	263.882
4	1.059	0.407	10.590	3.593	339.282
5	1.058	1.272	10.580	3.728	352.363
6	1.059	2.144	10.590	3.856	364.117
7	1.060	3.018	10.600	3.982	375.660
8	1.062	3.891	10.620	4.109	386.911
9	1.063	4.761	10.630	4.239	398.777
10	1.064	5.633	10.640	4.367	410.432

Interpolated at VCE = 3.0 V

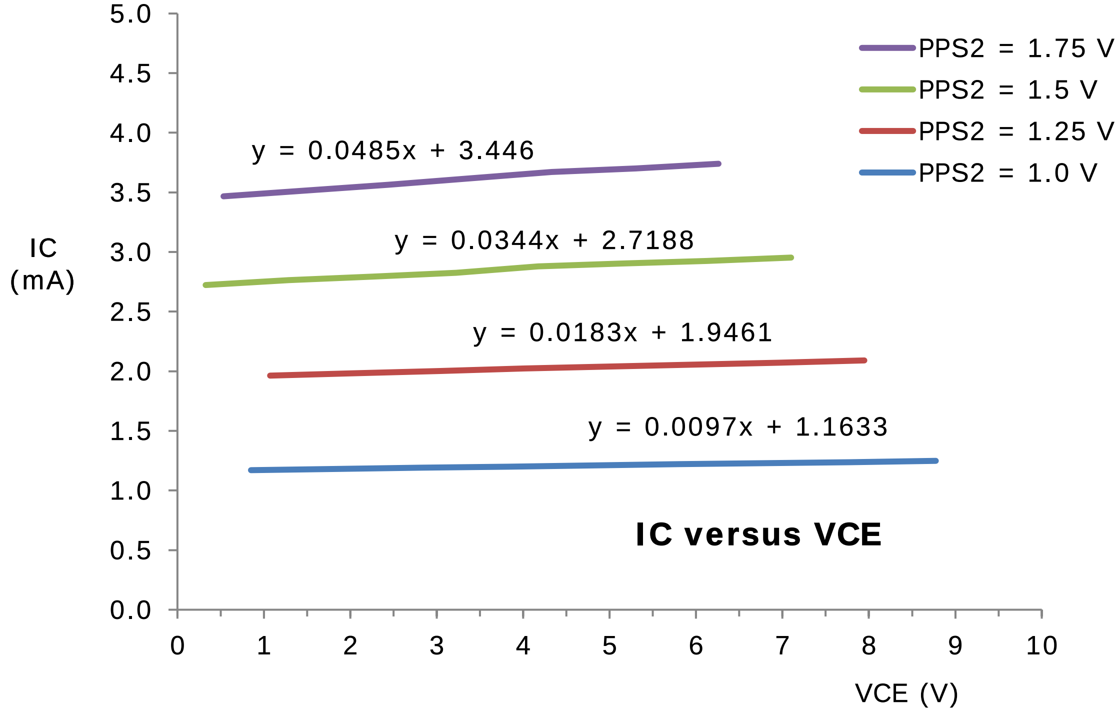
6.979	1.060	3.000	10.600	3.979	375.423

4.3 Analysis

1. Graph of individual curves of IC versus VCE. All the curves tilt up.



2. Using measurements taken on the ***without*** the bypass resistor connected, compute the slopes of the straight parts of output curves in units of Ω^{-1} (or Mhos, Siemens, or S).



Taken from the trendlines

PPS2 (V)	ICsat (mA)	Slope (mA/V = mS)	VA (V)	λ = Slope/ICsat (1/V)
1.00	1.1633	0.0097	119.928	0.00834
1.25	1.9461	0.0183	106.344	0.00940
1.50	2.7188	0.0344	79.035	0.01265
1.75	3.4460	0.0485	71.052	0.01407

3. The value of the BJT output conductance will tend to increase in proportion to the collector current IC. The output conductance is usually expressed as λI_{Csat}, where λ is a constant with units of V^{-1}. Calculate IC_{sat} at VCE = 0 and VA at IC = 0 on each fitted line (as if the straight part was extended.)

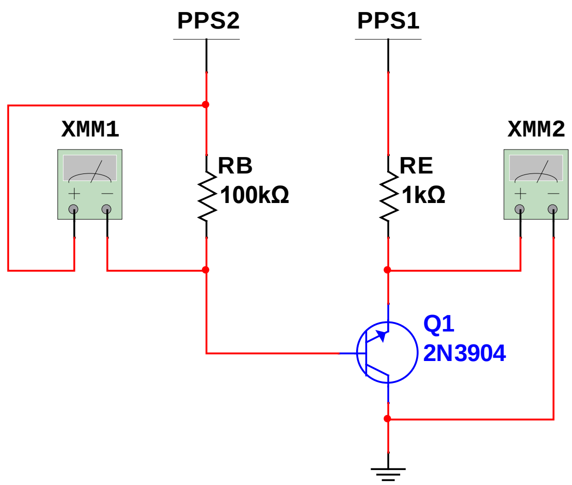
   As above.

4. Find the best fit value of λ which allows the forward-active output curves to be well approximated by the relationship $IC = IC_{sat} (1 + \lambda VCE)$.

   As above.

5.2 Measurements

For this circuit, here were my measurements, likely typical.



Measured values (Ω)

RB	99,080
RB	982

PPS2 = 1.0 V

PPS1	VRB	VEC	IB (μA)	IE (mA)	IE / IB
0	0.478	0.000	4.824	0.000	-0.018
1	0.478	0.987	4.824	0.013	2.786
2	0.478	1.986	4.824	0.015	3.018
3	0.478	2.985	4.824	0.015	3.082
4	0.478	3.985	4.824	0.015	3.208
5	0.478	4.985	4.824	0.016	3.230
6	0.477	5.983	4.814	0.017	3.511
7	0.475	6.981	4.794	0.019	4.015
8	0.472	7.978	4.764	0.023	4.767
9	0.467	8.969	4.713	0.032	6.698
10	0.453	9.942	4.572	0.059	12.963
Interpolated at VEC = 3.0 V					
3.015	0.478	3.000	4.824	0.015	3.084

PPS2 = 1.25 V

PPS1	VRB	VEC	IB (μA)	IE (mA)	IE / IB
0	0.717	0.000	7.237	0.000	-0.005
1	0.716	0.981	7.226	0.020	2.711

2	0.716	1.979	7.226	0.021	2.934
3	0.716	2.979	7.226	0.022	3.016
4	0.716	3.978	7.226	0.023	3.157
5	0.716	4.977	7.226	0.024	3.269
6	0.715	5.975	7.216	0.026	3.556
7	0.714	6.971	7.206	0.029	4.056
8	0.710	7.966	7.166	0.035	4.888
9	0.704	8.951	7.105	0.050	7.051
10	0.686	9.891	6.924	0.112	16.105

Interpolated at VEC = 3.0 V

3.021	0.716	3.000	7.226	0.022	3.019

PPS2 = 1.5 V

PPS1	VRB	VEC	IB (μA)	IE (mA)	IE / IB
0	0.958	0.000	9.669	0.000	-0.001
1	0.958	0.974	9.669	0.026	2.717
2	0.958	1.972	9.669	0.028	2.928
3	0.958	2.971	9.669	0.029	3.044
4	0.958	3.970	9.669	0.031	3.170
5	0.957	4.969	9.659	0.032	3.321
6	0.956	5.966	9.649	0.035	3.620
7	0.955	6.961	9.639	0.040	4.141
8	0.952	7.952	9.608	0.049	5.055
9	0.947	8.931	9.558	0.071	7.394
10	0.921	9.807	9.296	0.197	21.187

Interpolated at VEC = 3.0 V

3.029	0.958	3.000	9.669	0.029	3.047

PPS2 = 1.75 V

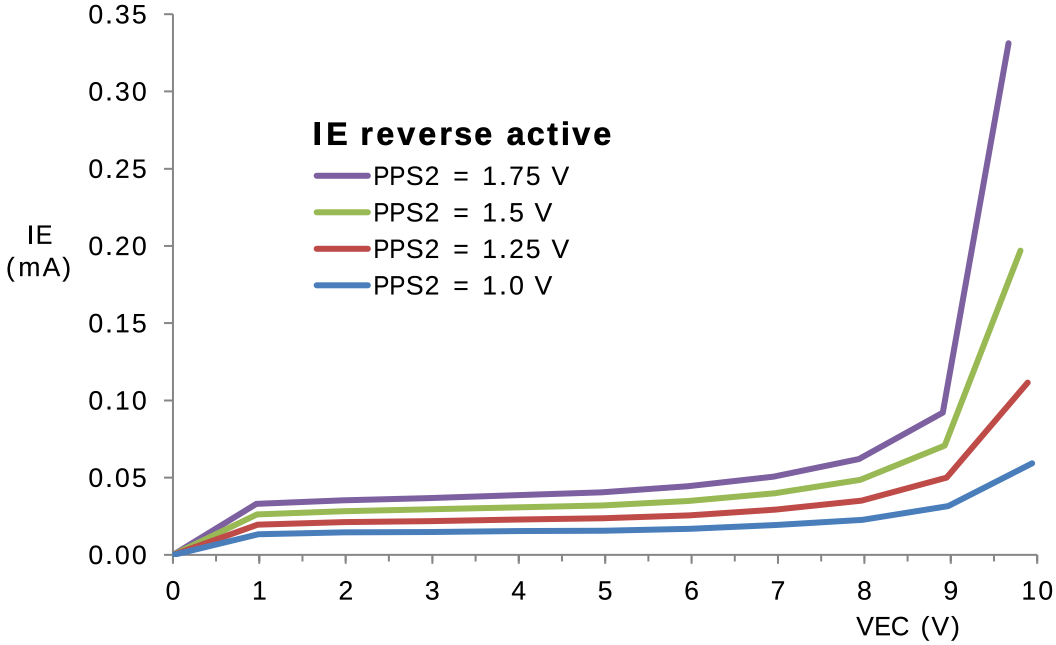
PPS1	VRB	VEC	IB (μA)	IE (mA)	IE / IB
0	1.202	0.000	12.020	0.000	-0.003
1	1.201	0.967	12.010	0.033	2.742
2	1.201	1.965	12.010	0.035	2.940
3	1.201	2.963	12.010	0.037	3.064
4	1.201	3.961	12.010	0.039	3.214
5	1.200	4.960	12.000	0.040	3.375
6	1.198	5.956	11.980	0.044	3.706
7	1.194	6.949	11.940	0.051	4.238
8	1.187	7.938	11.870	0.062	5.232
9	1.580	8.908	15.800	0.092	5.829
10	1.064	9.669	10.640	0.331	31.128

Interpolated at VEC = 3.0 V

3.037	1.201	3.000	12.010	0.037	3.070

5.3 Analysis

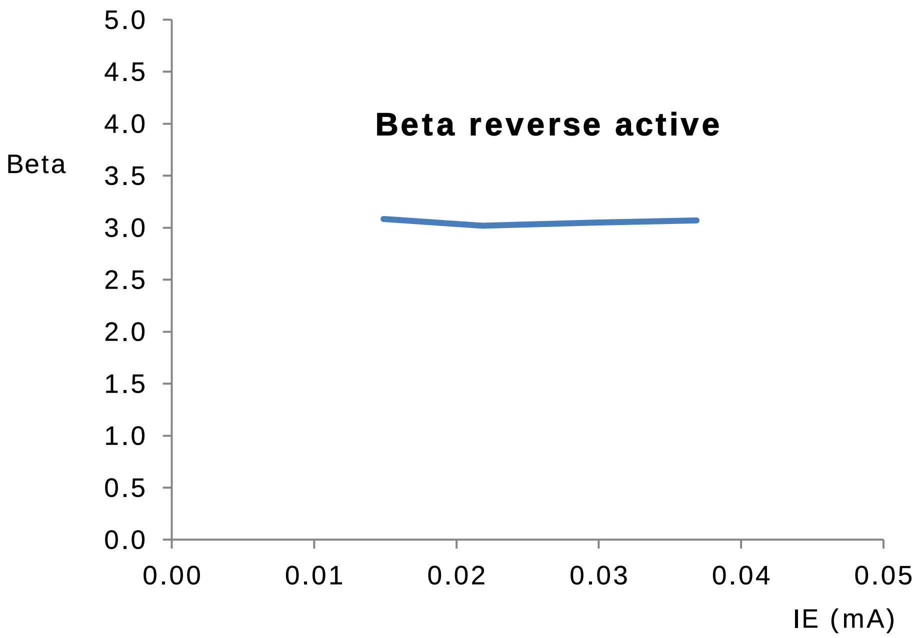
1. Graph of individual curves of IE versus VEC. In reverse active, there's very little current through the transistor until it hits breakdown at around 9 V.



2. Use interpolation with each set of measurements corresponding a given value of PP2 to find estimated values PPS1, VRB, IB, IE and β_R corresponding to VEC = 3.0 V.

   As above.

3. Create a plot of β_R versus IC at VEC = 3.0 V from your interpolated results.



4. Compare these results with those from your measurements in forward active.

   In reverse active, the transistor is not a very good amplifier.

5. If the base-emitter and base-collector junctions seemed fairly symmetric when measured with a multimeter, do they behave symmetrically in a circuit?

   Measured with a multimeter, there's very little difference between the BE and BC junctions. But the behavior in a circuit is not at all symmetric.