EXPERIMENT KW4: TEMPERATURE MEASUREMENT AND CALIBRATION

Related course: KIE3010 (Instrumentation)

OBJECTIVES:
1. To observe how the platinum resistance thermometer (PRT) works and linearity of PRT
2. To observe the linearity and accuracy of the liquid filled glass, gas (vapour) pressure and Bi-metal devices by calibration against the reference sensor
3. To observe how the NTC thermistor and thermocouples work and their linearity
4. To compare the linearity between J and K type thermocouples

EQUIPMENT:
PRT, Bi-metal devices, NTC thermistor, J and K type thermocouple

INSTRUCTIONS:
1. Record all your results and observations in a log book or on a piece of paper
2. Refer to the SAFETY WARNING below

SAFETY WARNING!!
- **Clean up any water spill immediately.**
- **If water is spilled on the equipment, disconnect the electrical supply and dry the equipment.**
- **Never touch any electrical parts with wet hands.**
- **Boiling water is dangerous and creates steam. Keep away from the hot water. Always allow the hot water to cool down to at least 70°C before drain it away.**
- **Ice can damage skin. Always use suitable gloves or tools to hold ice.**

REFERENCE(S):
Refer to the main references of KIE3010

TESTS:
TEST 1: Calibration of PRT
TEST 2: Calibration of liquid filled glass, gas (vapour) pressure and bi-metal devices
TEST 3: Calibration of NTC thermistor
TEST 4: Calibration of J and K type thermocouples

INTRODUCTION:

Resistance temperature detectors (RTDs) are sensors used to measure temperature by correlating the resistance of the RTD element with temperature. Most RTD elements consist of a length of fine coiled wire wrapped around a ceramic or glass core. The RTD element is made from a pure material, typically platinum, nickel or copper. The material has a predictable change in resistance as the temperature changes. Platinum is the best metal for RTDs because it follows a very linear resistance-temperature relationship.

The significant characteristic of metals used as resistive elements is the linear approximation of the resistance versus temperature between 0 and 100 °C. The temperature coefficient of resistance is called alpha, α in Ohm/Ohm/°C, where R_0 and R_{100} are the resistance of the sensor at 0 °C and 100 °C respsectively, $\alpha = (R_{100} - R_0) / (100R)$.

Calibration is a process of finding a relationship between two unknown quantities when the measurable quantities are not given a particular value for the amount considered or found a standard for the quantity. When one of quantities is known (standard), which is made or set with one device, another measurement is made as similar way as possible with the first device using a second device (unit under test).

Thermistors are temperature-sensing elements made of semiconductor that has been sintered to display large changes in resistance proportional to small changes in temperature. This resistance can be measured by passing a small direct current through the thermistor to measure the voltage drop produced. Negative temperature coefficient (NTC) thermistors are non-linear resistors, where its resistance decreases as the temperature increases.

Thermocouples are sensor used to measure temperature. Thermocouples consist of two wire legs made from different metals. The wire legs are welded together at one end, creating a junction. This junction is where the temperature is measured. When the junction experiences a change in temperature, a voltage is created. There are many types of thermocouples, depending on the temperature range and chemical resistance. Thermocouples have low cost, high temperature limits and wide temperature ranges.

PROCEDURES:

1. Make sure the electrical power supply is OFF.
2. Close the drain valve at the back of the heater tank.
3. Unscrew the lid of the heater tank and fill it with approximately 1.5 liters of clean water so that it is half-full.
4. Close the lid of the heater tank.
5. Add ice to the icebox and put its lid on.
6. Make sure the heater switch is OFF.
7. Fit and adjust the black ‘O’ rings to each device that will be used. Adjust the ‘O’ ring so that each device is immersed in the heater tank water by between 70 mm and 80 mm as shown in Figure 1. If necessary, add more water to the Heater Tank.

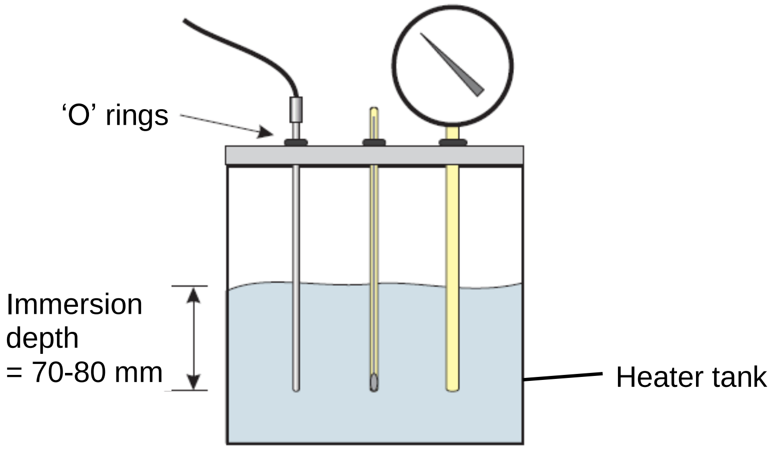

Figure 1

TEST 1: Calibration of PRT

Objectives: To observe how the platinum resistance thermometer (PRT) works and PRT linearity

1. Connect the reference sensor to its socket and connect the PRT to the millivoltmeter and the constant current source as shown in Figure 2. Note that the PRT is connected as a four wire device.
2. Put the reference sensor and the PRT into the icebox (through the holes in its lid). Wait a few minutes for the readings to stabilize.

3. Put both devices into the heater tank (through the holes in its lid). Switch ON the heater and note the reference temperature.
4. At intervals of 10°C (shown by the reference temperature), record the INPUT 1 readings of the millivoltmeter to complete Table 1.
5. Switch OFF the heater when the reference temperature is 85°C.

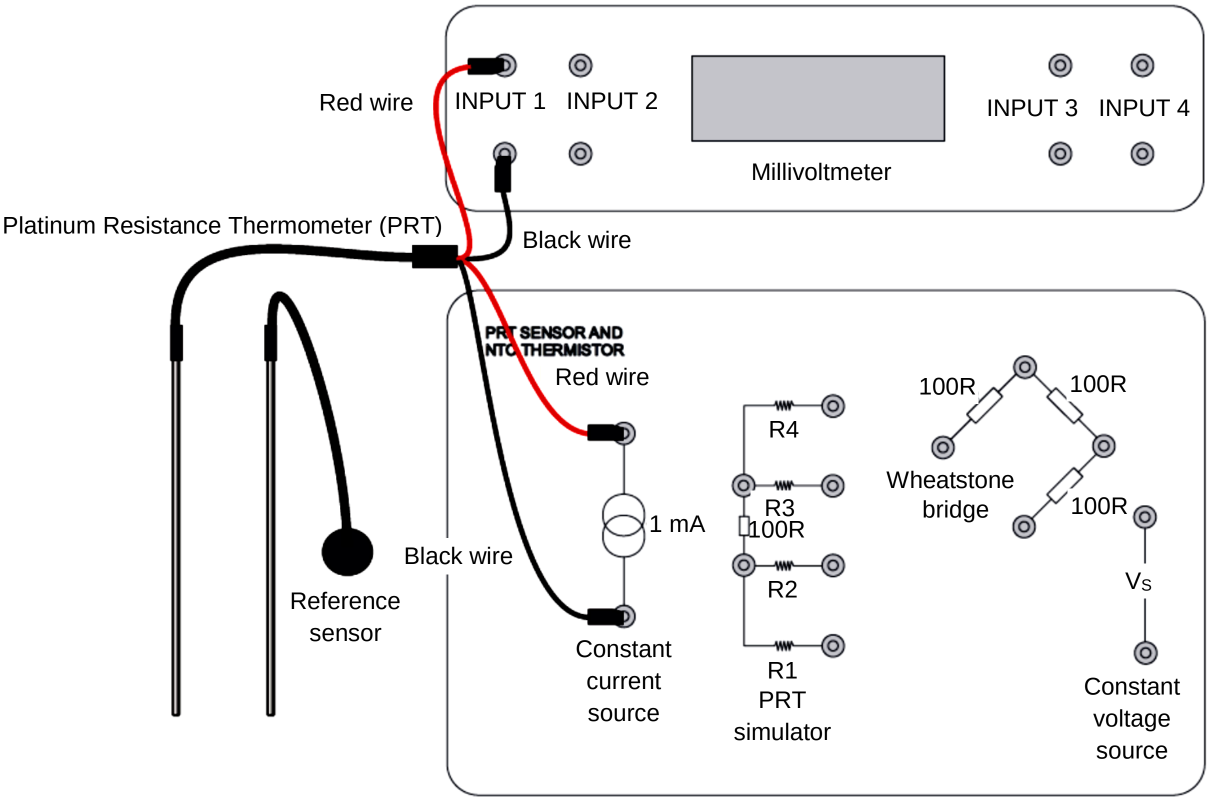

Figure 2

Table 1: Calibration of PRT

Reference temperature (°C)	Measured voltage (mV)	Calculated resistance (R_{calc}, Ω)	Standard resistance from Table A1 (R_{std}, Ω)	Difference between R_{calc} and R_{std} (R_{diff}, Ω)	Error = $\lvert R_{diff}/R_{std}\rvert$ x 100 (%)
35					
45					
55					
65					
75					
85					

AQ1. Given that the constant current is 1 mA, use Ohm's law to calculate the resistance of the PRT for each row in Table 1.

AQ2. From Table 1, plot a graph of the calculated resistance R_{calc} (y-axis) vs. reference temperature (x-axis). Then, draw the best curve for this graph.

AQ3. From Table 1, plot a graph of the standard resistance R_{std} (y-axis) vs. reference temperature in the same graph in AQ2. Then, draw the best straight line for this graph.

AQ4. From the results, explain why we can use the PRT as an accurate reference sensor.

AQ5. Identify any possible causes of error between R_{calc} and R_{std}.

TEST 2: Calibration of liquid filled glass, gas (vapour) pressure and bi-metal devices

Objectives: To observe the linearity and accuracy of the liquid filled glass, gas (vapour) pressure and bi-metal devices by calibration against the reference sensor

1. Choose one of the liquid filled glass thermometers (Item 6). Put the reference sensor and the thermometer into the icebox (through the holes in its lid). Wait a few minutes for the readings to stabilize.
2. Put both devices into the heater tank (through the holes in its lid). Switch ON the heater and observe the reference temperature.
3. At intervals of 10°C (shown by the reference temperature), record the readings of the thermometer to complete Table 2.
4. Switch OFF the heater when the reference temperature is 85°C.
5. Repeat the experiment for the other liquid filled glass thermometer (Item 7), the gas (vapour) pressure thermometer and the bi-metal thermometer. Allow the heater water to cool down (and change it if necessary for cooler water) between tests.

Notes: The gas (vapour) pressure and bi-metal thermometers have a mechanical gauge. Hence, gently ‘tap’ them with your fingers before recording their reading. This removes any static friction in their mechanism, which would give false readings.

BQ1. From Table 2, plot a graph of the measured temperature T_{meas} (y-axis) vs. reference temperature T_{ref} (x-axis) for each device separately.

BQ2. For each graph in BQ1, add a graph of the reference temperature T_{ref} vs. reference temperature T_{ref} and draw its best straight curve. This is called the reference curve.

BQ3. Compare both devices against the reference to identify which one is more accurate.

BQ4. Identify any possible causes of error between T_{ref} and T_{meas}.

Table 2: Calibration of liquid filled glass thermometers

Reference temperature (T_{ref}, ^{0}C)	Item 6			Item 7		
	Measured temperature (T_{meas}, ^{0}C)	Difference between T_{ref} and T_{meas} (T_{diff}, Ω)	Error = $\|T_{diff}/T_{ref}\|$ x 100 (%)	Measured temperature (T_{meas}, ^{0}C)	Difference between T_{ref} and T_{meas} (T_{diff}, Ω)	Error = $\|T_{diff}/T_{ref}\|$ x 100 (%)
35						
45						
55						
65						
75						
85						

TEST 3: Calibration of NTC thermistor

Objectives: To observe how the NTC thermistor and thermocouples work and their linearity

1. Connect the reference sensor to its socket and connect the NTC Thermistor (Item 10) to the millivoltmeter and the constant current source as shown in Figure 3.
2. Put the reference sensor and the NTC Thermistor into the icebox (through the holes in its lid). Wait a few minutes for the readings to stabilize.
3. Put both devices into the heater tank (through the holes in its lid). Switch ON the heater and observe the reference temperature.

4. At intervals of 10°C (shown by the reference temperature), record the INPUT 1 readings of the millivoltmeter.
5. Switch OFF the heater when the reference temperature is 85°C.

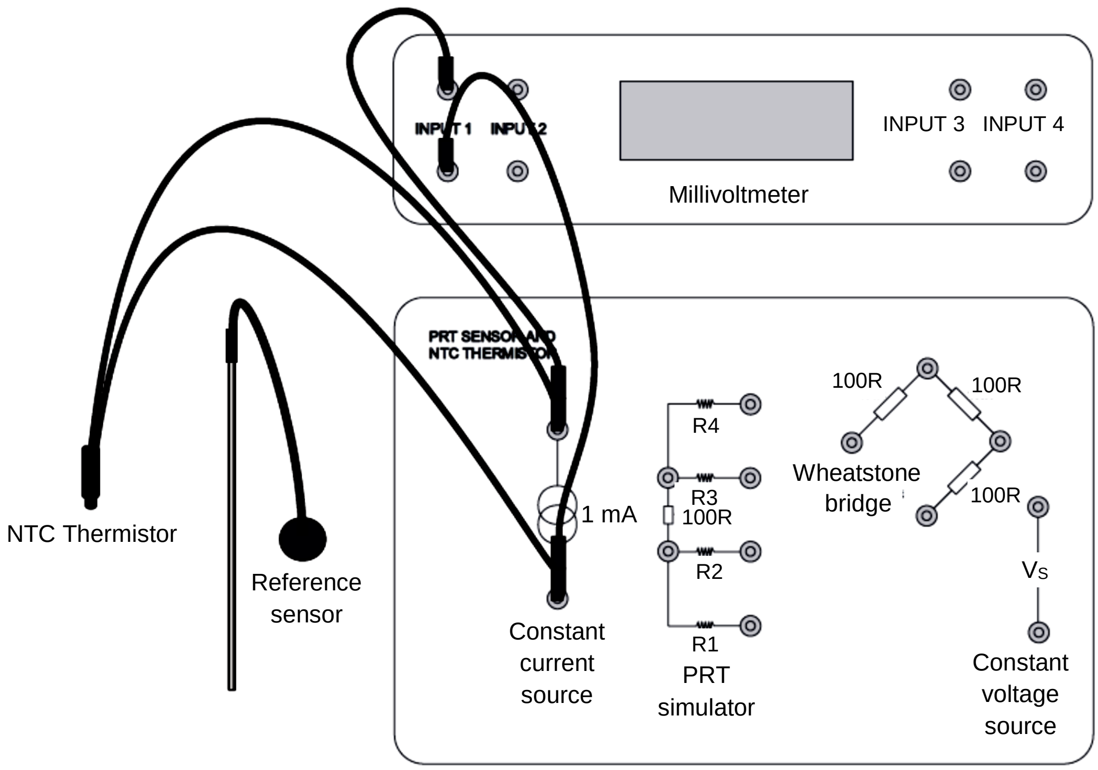

Figure 3

Table 3: Calibration of NTC thermistor

Reference temperature (^{0}C)	Measured voltage (mV)	Calculated resistance (R_{calc}, Ω)	Standard resistance from Table A2 (R_{std}, Ω)	Difference between R_{calc} and R_{std} (R_{diff}, Ω)	Error = $\|R_{diff}/R_{std}\|$ x 100 (%)
35					
45					
55					
65					
75					
85					

CQ1. Given that the constant current is 1 mA, use Ohm's law to calculate the resistance of the thermistor for each row in Table 3.

CQ2. From Table 3, plot a graph of the calculated resistance R_{calc} (y-axis) vs. reference temperature (x-axis). Then, draw the best curve for this graph.

CQ3. From Table 3, plot a graph of the standard resistance R_{std} (y-axis) vs. reference temperature in the same graph in CQ2. Then, draw the best straight line for this graph.

CQ4. Identify any possible causes of error between R_{calc} and R_{std}.

TEST 4: Calibration of J and K type thermocouples

Objectives: To compare the linearity between J and K type thermocouples

1. Connect the reference sensor to its socket and connect J or K type thermocouple (Item 8 or 9) to the amplifier and millivoltmeter as shown in Figure 4. The amplifier amplifies the voltage from the thermocouple by 20, which makes it suitable for the millivoltmeter. Hence, the actual voltage from the thermocouple is 1/20 of the millivoltmeter reading.
2. Put the reference sensor and the thermocouple into the icebox (through the holes in its lid). Wait a few minutes for the readings to stabilize.
3. Put both devices into the heater tank (through the holes in its lid). Switch ON the heater and observe the reference temperature.
4. At 10°C interval (shown by the reference temperature), record the INPUT 1 readings of the millivoltmeter.
5. Switch OFF the heater when the reference temperature is 85°C.
6. Repeat the procedure for the other thermocouple.

DQ1. From Table 4, plot a graph of the measured voltage V_{meas} vs. reference temperature for each thermocouple separately. Then, draw the best fit curve for each graph.

DQ2. The graph should be reasonably linear but the errors between the measurement and standard may be large and consistent (an offset). Identify the causes of any errors.

DQ3. Why thermocouple connections are important? Why thermocouple cannot be connected directly to an ordinary measuring device?

Table 4: Calibration of J and K type thermocouples

Reference tempe-rature (^{0}C)	J type thermocouple				K type thermocouple			
	Measured voltage divided by 20 (V_{meas}, μV)	Standard voltage from Table A3 (V_{std}, μV)	Difference between V_{meas} and V_{std} (V_{diff}, Ω)	Error = V_{diff}/V_{std} x 100 (%)	Measured voltage divided by 20 (V_{meas}, μV)	Standard voltage from Table A4 (V_{std}, μV)	Difference between V_{meas} and V_{std} (V_{diff}, Ω)	Error = V_{diff}/V_{std} x 100 (%)
35								
45								
55								
65								
75								
85								

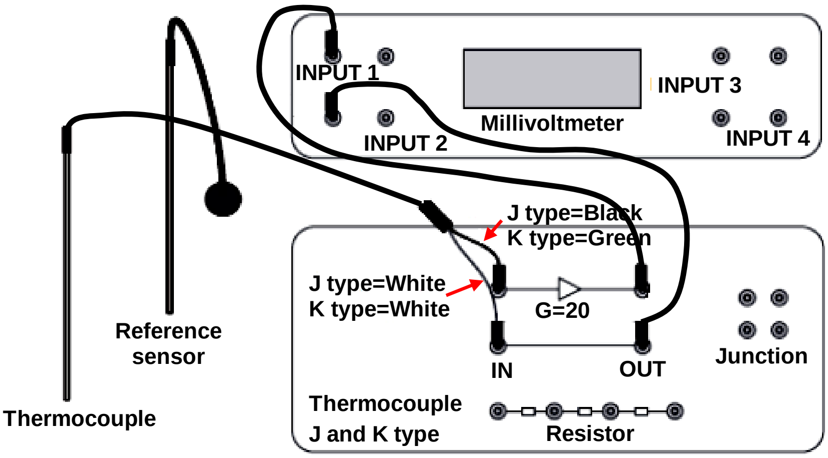

Figure 4

END OF EXPERIMENT

APPENDICES

Table A1: NTC Thermistor standards

°C	Ω	°C	Ω
0	261.0	**55**	37.82
5	212.6	**60**	32.64
10	174.4	**65**	28.33
15	144.2	**70**	24.70
20	119.9	**75**	21.57
25	100.0	**80**	18.91
30	84.18	**85**	16.65
35	71.08	**90**	14.71
40	60.32	**95**	13.02
45	51.42	**100**	11.56
50	44.04		

Table A2: PT100 (PRT) - resistance temperature detector standards

°C	Ω	°C	Ω	°C	Ω	°C	Ω	°C	Ω
0	100.00								
1	100.39	**21**	108.18	**41**	115.93	**61**	123.63	**81**	131.28
2	100.78	**22**	108.57	**42**	116.31	**62**	124.01	**82**	131.66
3	101.17	**23**	108.96	**43**	116.70	**63**	124.39	**83**	132.04
4	101.56	**24**	109.35	**44**	117.08	**64**	124.77	**84**	132.42
5	101.95	**25**	109.73	**45**	117.47	**65**	125.16	**85**	132.80
6	102.34	**26**	110.12	**46**	117.86	**66**	125.54	**86**	133.18
7	102.73	**27**	110.51	**47**	118.24	**67**	125.93	**87**	133.57
8	103.12	**28**	110.90	**48**	118.63	**68**	126.31	**88**	133.95
9	103.51	**29**	111.29	**49**	119.01	**69**	126.69	**89**	134.32
10	103.90	**30**	111.67	**50**	119.40	**70**	127.07	**90**	134.71
11	104.29	**31**	111.67	**51**	119.78	**71**	127.46	**91**	135.09
12	104.68	**32**	112.06	**52**	120.17	**72**	127.84	**92**	135.47
13	105.07	**33**	112.83	**53**	120.55	**73**	128.22	**93**	135.85
14	105.46	**34**	113.22	**54**	120.93	**74**	128.61	**94**	136.23
15	105.85	**35**	113.61	**55**	121.32	**75**	128.99	**95**	136.61
16	106.24	**36**	114.00	**56**	121.71	**76**	129.37	**96**	136.99
17	106.63	**37**	114.38	**57**	122.09	**77**	129.75	**97**	137.37
18	107.02	**38**	114.77	**58**	122.47	**78**	130.13	**98**	137.75
19	107.40	**39**	115.15	**59**	122.86	**79**	130.52	**99**	138.13
20	107.79	**40**	115.54	**60**	123.24	**80**	130.90	**100**	138.51

Table A3: J Type Thermocouple Standards

°C	µV	°C	µV	°C	µV	°C	µV	°C	µV
0	0								
1	50	**21**	1071	**41**	2111	**61**	3169	**81**	4240
2	101	**22**	1122	**42**	2164	**62**	3222	**82**	4294
3	151	**23**	1174	**43**	2216	**63**	3275	**83**	4348
4	202	**24**	1226	**44**	2269	**64**	3329	**84**	4402
5	253	**25**	1277	**45**	2322	**65**	3382	**85**	4456
6	303	**26**	1329	**46**	2374	**66**	3436	**86**	4510
7	354	**27**	1381	**47**	2427	**67**	3489	**87**	4564
8	405	**28**	1433	**48**	2480	**68**	3543	**88**	4618
9	456	**29**	1485	**49**	2532	**69**	3596	**89**	4672
10	507	**30**	1537	**50**	2585	**70**	3650	**90**	4726
11	558	**31**	1589	**51**	2638	**71**	3703	**91**	4781
12	609	**32**	1641	**52**	2691	**72**	3757	**92**	4835
13	660	**33**	1693	**53**	2744	**73**	3810	**93**	4889
14	711	**34**	1745	**54**	2797	**74**	3864	**94**	4943
15	762	**35**	1797	**55**	2850	**75**	3918	**95**	4997
16	814	**36**	1849	**56**	2903	**76**	3971	**96**	5052
17	865	**37**	1902	**57**	2956	**77**	4025	**97**	5106
18	916	**38**	1954	**58**	3009	**78**	4079	**98**	5160
19	968	**39**	2006	**59**	3062	**79**	4133	**99**	5215
20	1019	**40**	2059	**60**	3116	**80**	4187	**100**	5269

Table A4: K Type Thermocouple Standards

°C	µV	°C	µV	°C	µV	°C	µV	°C	µV
0	0								
1	39	**21**	838	**41**	1653	**61**	2478	**81**	3308
2	79	**22**	879	**42**	1694	**62**	2519	**82**	3350
3	119	**23**	919	**43**	1735	**63**	2561	**83**	3391
4	158	**24**	960	**44**	1776	**64**	2602	**84**	3433
5	198	**25**	1000	**45**	1817	**65**	2644	**85**	3474
6	238	**26**	1041	**46**	1858	**66**	2685	**86**	3516
7	277	**27**	1081	**47**	1899	**67**	2727	**87**	3557
8	317	**28**	1122	**48**	1941	**68**	2768	**88**	3599
9	357	**29**	1163	**49**	1982	**69**	2810	**89**	3640
10	397	**30**	1203	**50**	2023	**70**	2851	**90**	3682
11	437	**31**	1244	**51**	2064	**71**	2893	**91**	3723
12	477	**32**	1285	**52**	2106	**72**	2934	**92**	3765
13	517	**33**	1326	**53**	2147	**73**	2976	**93**	3806
14	557	**34**	1366	**54**	2188	**74**	3017	**94**	3848
15	597	**35**	1407	**55**	2230	**75**	3059	**95**	3889
16	637	**36**	1448	**56**	2271	**76**	3100	**96**	3931
17	677	**37**	1489	**57**	2312	**77**	3142	**97**	3972
18	718	**38**	1530	**58**	2354	**78**	3184	**98**	4013
19	758	**39**	1571	**59**	2395	**79**	3225	**99**	4055
20	798	**40**	1612	**60**	2436	**80**	3267	**100**	4096