Lab: Logic, Flow Control, Loops

Question 1 (20 minutes): Savings from Solar Energy

An office building has a solar panel array of 350 solar panels on the roof. The panels are capable of producing electricity from sunrise to sunset. On a particular day, the solar panel actively produces power for 18 hours.

Task 1: Using data from Table 1 and Table 2 below, calculate the total energy (unit in kWatt-hour) produced by the 350 panel array during the 18 hours.

Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Sunlight Condition Number	1	1	1	2	2	3	3	3	4	4	4	4	3	3	1	3	2	1

Table 1. Sunlight condition for each of the 18 hours.

Note: the units for the "Savings" column in table below is <u>Watt-hour</u>, not Watts!.

Sunlight Condition Number	Sunlight Condition	Power Output of 1 Panel	Savings per <u>Watt-hour</u> ($)
1	Minimum	20 Watts	0.00009
2	Mild	30 Watts	0.0002
3	Strong	50 Watts	0.0009
4	Intense	120 Watts	0.0016

Table 2.

Note: Power is the *rate* of energy consumption. Power*time = energy

Hint: 1) Enter data from Table 1 into a row vector. Enter power output data from Table 2 into a vector, 2) Iterate through the 18 hours using a loop, and 3) calculate and sum up the energy produced in each hour.

Task 2: Using the "Savings per Watt-hour" data from Table 2, what is the savings for using the solar array on this day?

Task 3: On cloudy days, it is estimated that the strength of sunlight for minimum and mild conditions is decreased by 50%, and decreases by 30% for strong and intense conditions. As a result, the power output of a single panel listed in table above during those conditions is also decreased by the same percentages. Re-calculate the total energy (unit: kWatt-hour) produced by the array if it is a cloudy day.

Task 4: What is the cost savings on a cloudy day?

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Question 2 (20 minutes): Solar Panel Rental

RentUhWatt is a company that rents out solar panels to its customers. The company makes money by 1) charging each customer a monthly rental fee, and 2) selling the unused electricity from each customer back to the electricity company. The company spends an initial cost of 100,000 dollars to purchase 5,000 solar panels. The 5,000 panels are rented out to customers according to the rules below:

1) For each customer:

Total energy available for sale = total energy generated – total energy consumed

2) The company's monthly income (revenue):

Monthly revenue = rental fee + total energy sold * cost per kWh

Task 1: What is the company's total monthly revenue? Assuming the company has 17 customers, and their energy usage as shown in table below? Assume 400 kWh is the energy generated every month for every customer, and each customer's rental fee is $20 per month. Electricity is sold back to the electricity company at 5 cents per kWh. <u>You do not lose money if the customer consumes too much energy – you simply don't sell any energy back to the electricity company on that month.</u>

Customer	Average Energy Consumed Each Month (kWh)		Customer	Average Energy Consumed Each Month (kWh)
1	200		11	310
2	170		12	370
3	150		13	380
4	260		14	50
5	20		15	430
6	430		16	180
7	300		17	400
8	320			
9	310			
10	460			

Task 2: Again, using the data in the table above, how long until RentUhWatt breaks even? Break even is the point at which the initial cost (money spent by business owner to get the business up and running) is recovered through profits. Assume same conditions in Task 1.

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Question 3 (20 minutes): Solar Array Sizing

A customer would like to install a solar panel array for his small business. The daily peak power is estimated to be 50 kW and his budget is $10,000.

Task 1: If the price for a single solar panel is $50, given the volume discount table below, how many solar panels can he afford? (Hint: see bottom of problem)

Number of panels purchased	Discount per panel
1 – 5	0%
6-29	10%
30 – 99	15%
100+	20%

Task 2: Now, assuming each solar panel can supply 40 Watts, how much does it cost for his business to become 100% off-the-grid? Don't forget to include the volume discount! (Hint: see bottom of problem)

Off-the-grid means to be completely powered from renewable energy. In this case is solar energy.

Hint: Use a loop to solve this problem. Use the loop index to represent the number of solar panels, and change the discount percentage as necessary for each loop iteration.

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Question 4 (10 minutes): Financing for Solar Power
To install the solar panel array, a customer borrows $50,000 from the bank at a yearly *compound* interest rate of 1%. The duration of the loan is 30 years.

The simplified formula to calculate the amount of money (including interest), A, accumulated after n years, including (compound) interest is: $A=P(1+r)^n$ where P is the principal loan amount, r is the annual compound interest rate, and n is the loan duration (years).

Task 1: Use a loop to calculate the total amount (principal+interest) that the customer must pay back to the bank at the end of the loan duration.

Task 2: Check your answer from Task 1 with the formula given above. $A=P(1+r)^n$. What is A calculated using the formula?

Task 2: What is the average monthly payment?
Task 3: What is the interest paid every month?

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Question 5 (20 minutes): Modeling Solar Cell using Taylor Series

The equation that governs the operation of a solar cell is below.

$I_{solar\ cell}(V) = I_{light} + I_{dark} - I_{dark}e^{\left(\frac{V}{Vt}\right)}$ -- Equation (1)
$where$

$I_{light} = 500 * 10^{-3} Amps, I_{dark} = 0.6 * 10^{-6} Amps, Vt = 26 * 10^{-3} Volts$

The Taylor series is a mathematical tool that allows the output of a continuous function to be approximated using a series of terms. The Taylor series for e^x is shown below. The pattern for constructing successive terms is shown in the summation. The first four terms used in the approximation are shown.

$Taylor\ series\ for\ e^x = \sum_{n=0}^{\infty} \frac{x^n}{n!} = 1 + x + \frac{x^2}{2!} + \frac{x^3}{3!} + \cdots$ -- Equation (2)

Task 1: Use Taylor series to approximate $I_{solar\ cell}(V)$ to just 5 terms, with $V = 0.3\ volts$. Use a loop.

Task 2: Now still using V=0.3 volts, approximate $I_{solar\ cell}(V)$ to 20 terms. Use a loop.

Task 3: Re-write your code such that the program stops the approximation when the absolute value of the term that was added last is smaller than 0.0001. Display the number of iterations to achieve the above condition.

Task 4: Re-write your code such that the program stops the approximation when the approximated value is within 1% (% error) of the real value. Hint: Calculate the actual (not approximated) value of $I_{solar\ cell}(V)$ using equation (1), and compare it to the value approximated by Taylor series (equation (2)). Display the number of iterations to achieve the above condition.

$$percent\ error = \left|\frac{calculated - approximated}{calculated}\right|$$

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Question 6 (20 minutes): Investing in Solar Power
Solar power is one area of investment within the energy sector. This problem will look at a few things related to investing in solar energy.

Task 1: If the cost-per-kWh for solar power drops by 5% every 3 months and the cost-per-kWh of conventional electricity increases at 2% every 9 months, calculate the number of years it will take for the cost of solar power to become comparable to conventional electricity. Assume solar power is currently 22 cents per kWh and conventional electricity is 7 cents per kWh.

Hint: Use a loop to solve this problem. Use the loop index to represent the month and increment it every loop iteration. Update the cost per watt at appropriate times.

Task 2: You recently invested $10,000 in a company through stocks, which translates to 520 shares at $19.23 per share. You wish to sell your stock when the value of your investment doubles, which is $20,000. If the company forecasts that its stock price will grow at a rate of 4% every 3 months, how many months do you need to wait before selling your stocks? (This task is not related to Task 1. However, this problem may be solved using the same approach)

Hint: Use a loop to solve this problem. Use the loop index to represent the month and increment it every loop iteration. Update the total value of the investment at appropriate times.

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Question 7 (20 minutes): Electric Vehicle Issues

In 2007, there are more than 250 million vehicles registered in the United States. In this question, we will explore one potential problem introduced by transitioning from gasoline to electricity powered vehicles.

The table below shows some information for 4 types of electric vehicles. Information includes battery size, range (distance before battery recharge), number of EVs of this type in the US, and the average usage profile.

Electric Vehicle Type	Battery Capacity	Recharge Requirement	Range	Number of Vehicles
EV1	24 kWh	every day	117 km	16 million
EV2	24 kWh	every 4 days	370 km	27 million
EV3	24 kWh	every 3 days	200 km	1 million
EV4	24 kWh	every 2 days	190 km	4 million

Task 1: Calculate the total number of recharges by all four electric vehicle types (all EV types together, not individual EV types) in 31 days. Use a loop. Note: each recharge is 20 kWh.

Hint: loop through 31 days, and write code to check which EV requires a recharge on each day.

Task 2: Using data in table above, what is the additional load (energy, kWh) on the power grid in 31 days? Additional load = number of vehicles * number of recharges * energy per recharge

Task 3: What is the range-per-kWh for each vehicle?

Task 4: Solar panels (shown in table below) are installed on top of each vehicle to increase the EV's range. What is the new range-per-kWh of each EV with solar panels installed? Hint: use the formulas below to help you.

1) Solar power = total solar panel area * power per area * hours active
2) New range = Original range (from table) +
   Original range-per-kwh (from Task 3) * solar power

Electric Vehicle Type	Solar Panel Area (square meters)	Power (watts) per square meter	Hours active per day
EV1	6	200	8
EV2	8	500	3
EV3	4	400	4
EV4	8	700	6

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Question 8: Maximum Power Point Tracking in Solar Panels

In solar panel systems, the solar panel is never directly connected to the load as shown in Figure 1, because in this configuration, any change in the load directly affects the solar panel's output. Typical solar panel systems utilize a controller in between the panel and the load as shown in Figure 2 below. The controller prevents any changes in the load from affecting the solar panel's output. In other words, the controller *regulates* the solar panel's output such that the maximum amount of solar power is delivered to the load under all illumination conditions.

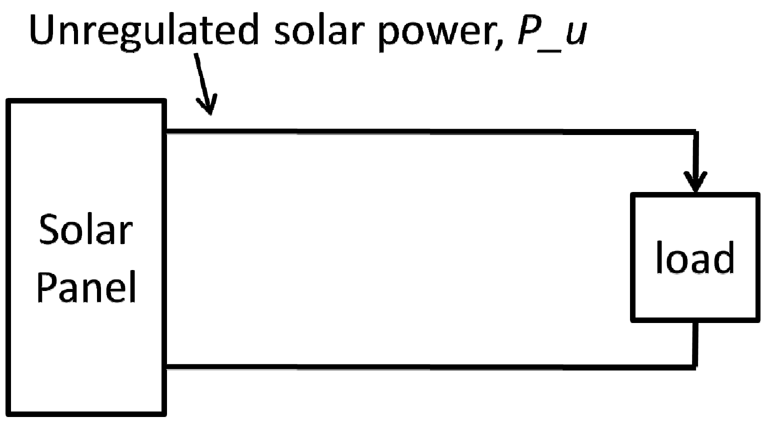

Figure 1 Unregulated Solar Panel Configuration.

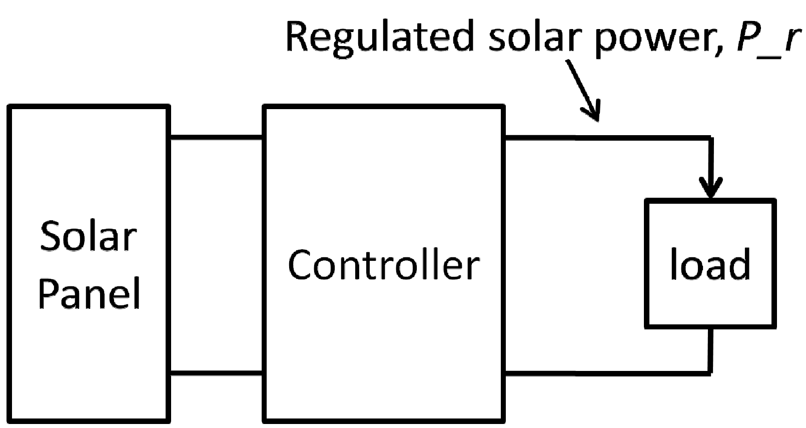

Figure 2 Regulated Solar Panel Configuration.

In this problem, we will explore the benefits of using a controller. Figures 1 and 2 above has the power delivered to the load labeled as ***P_u***, the panel's *unregulated* output power, and ***P_r***, the panel's *regulated* output power. We will write code to compute and plot the two quantities.

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Task 0 (0 pts.): Load the variables in "illum.mat" using the load command. You now have three 1D/2D vectors in the workspace. They are as follows:

illumination: This is a 10x6 matrix. Column 1 contains illumination levels (500 lux to 1400 lux), and columns 2 to 6 contains the corresponding current ('isc') values measured throughout 5 trials. Below is a table representing this vector

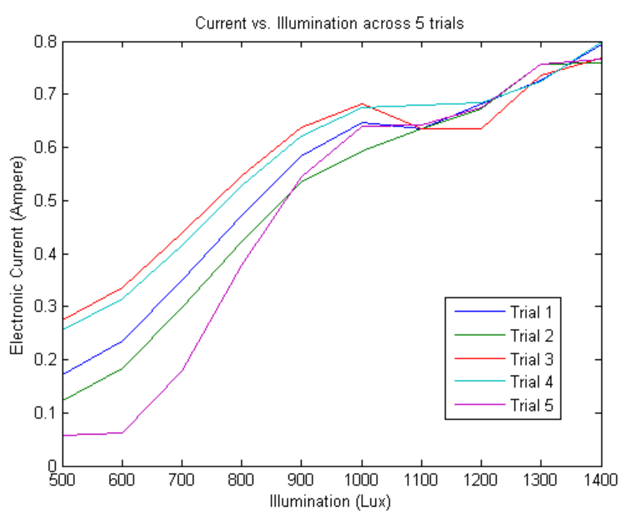
Illumination	Electronic current ('isc')			
	Trial 1	Trial 2	…	Trial 5
500	0.21	0.23	…	0.20
600	0.3	0.31	…	0.42
…	…	…	…	…
1400	0.71	0.81	…	0.7

load_profile: This is a 150x1 vector that contains 150 points of load conditions. The column contains the average load (resistance).

illumination_profile: This is a 150x1 vector that contains 150 points of the illumination conditions.

Important: **load_profile** and **illumination_profile** were measured at the same time points. Each data point was taken at 1 minute intervals, so the vector contains data for 150 minutes.

Task 1 (1 pts.): Let's see what's inside **illumination**. Write code to plot columns 2 to 6 (y-axis) versus column 1 (x-axis), on the same plot. This is the electronic current, "current" data (current (on y-axis) versus illumination (x-axis), for the five trials. Your plot should look similar to figure below.



You can see that as illumination goes up, current increases. There are five curves. Each curve corresponds to one column (one trial).

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For tasks 2 to 10 below, all tasks are related and will build up to a single program.

Task 2 (1 pts.): Given an illumination level, write code to compute the average current throughout the 5 trials for that illumination. (use 700 lux for illumination to test your code)

Task 3 (2 pts.): Utilizing your code from Task 2, which computes the average current for a given illumination. Write code, using a loop, to compute the average current for each illumination condition value inside **illumination_profile**.

Task 4 (2 pts.): Adding onto the code from Task 3 and using the function 'panel_mpp()', write code to obtain the optimal voltage and current for each illumination condition value inside **illumination_profile**. See more information below about 'panel_mpp()'.

The function '[vmp imp]=panel_mpp(i_light,Nrow,Ncol)' returns the optimal operating voltage and currents, 'vmp' and 'imp', for a given illumination condition. This function takes three arguments. 'i_light' is the current corresponding to the illumination condition, Nrow and Ncol are the number of rows and columns in the solar panel. <u>Set Nrow to 35, and Ncol to 1.</u>

Task 5 (2 pts.): Adding onto the code from Task 4 and using the function 'pd()', obtain the photodiode voltage for each illumination condition inside **illumination_profile.** See more information below about 'pd()'.

The function 'vpd=pd(i_light)' gives the voltage of a photodiode given the current generated by the illumination.

Task 6 (2 pts.): The unregulated solar panel's voltage is the photodiode voltage (obtained in Task 5) multiplied by 'Nrow'. Calculate the unregulated solar panel voltage.

Task 7 (2 pts.): The unregulated solar panel's current is estimated to be the solar panel's voltage divided by the corresponding load condition (**load_profile**) at the same time point. Calculate the unregulated solar panel current.

Task 8 (2 pts.): Calculate ***P_r*** and ***P_u*** as follows:

The regulated power from the solar panel is equal to the optimal voltage multiplied by the optimal current (from Task 4). This is the regulated power, ***P_r*** as described in the beginning of the lab.

The unregulated power delivered to the load is equal to the solar panel's voltage multiplied by its current (from Tasks 6 and 7). This is the unregulated power, ***P_u*** as described in the beginning of the lab.

Task 9 (1 pts.): Write code so the calculated power numbers (regulated and unregulated) are stored for each loop iteration. End the loop here.

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Task 10 (1 pts): The loop is now finished. Write code to plot ***P_r*** and ***P_u*** on the same plot. Plot ***P_r*** using red asterisks, and plot ***P_u*** using blue asterisks. Label the plot using title(), xlabel(), and ylabel(). Create a legend using legend(). Your plot should look like the figure below.