parallel resistance. For the other, what is the parallel resistance in its equivalent circuit?

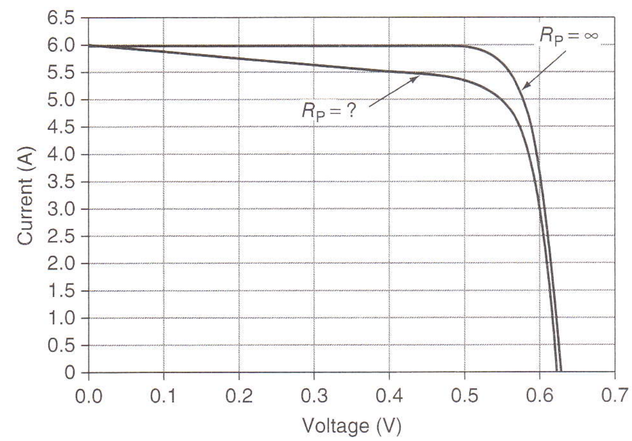

FIGURE P5.4

5.5 The following figure shows two *I–V* curves. Both have equivalent circuits with infinite parallel resistances. One circuit includes a series resistance while the other one does not. What is the series resistance for the cell that has one?

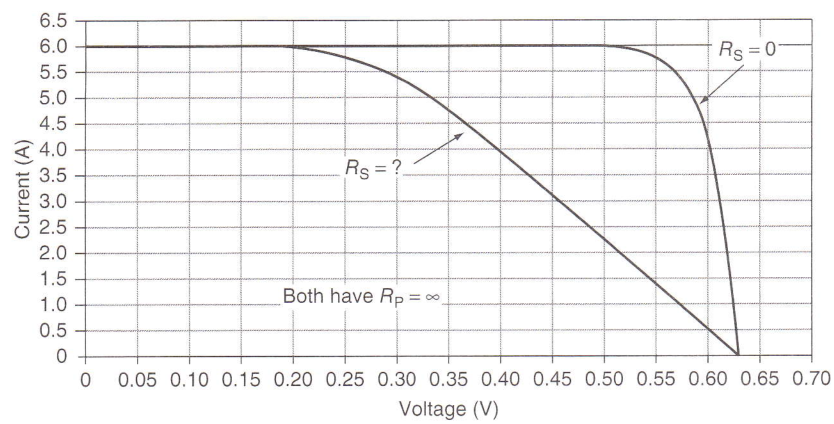

FIGURE P5.5

5.6 Recreate the spreadsheet that was started in Example 5.4 for a 72-cell, 233-W PV module for which the equivalent circuit of each cell has both series (0.001 Ω) and parallel resistances (10.0 Ω).

a. From your spreadsheet, what is the current, voltage, and power delivered when the diode voltage V_d is 0.4 V?

b. Plot the entire *I–V* curve for this module.

5.7 Consider how you might make a simple, cheap pyranometer out of a single small (e.g., 1 cm^2) PV cell along with a precision load resistor. The PV cell has the following *I–V* curve and the goal is for the digital multimeter (DMM, with infinite input resistance), when set on its millivolt DC scale, to give you direct readings of insolation.

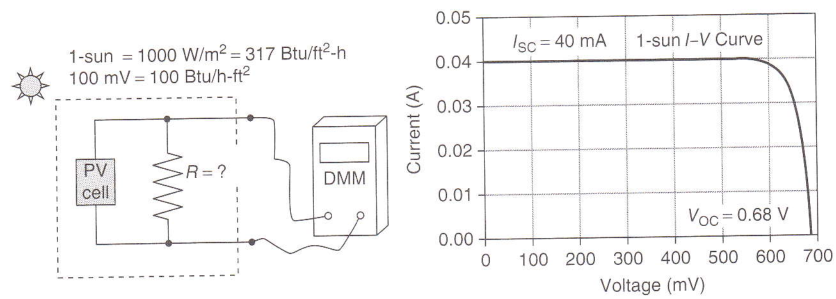

FIGURE P5.7

a. Find the load resistance that the pyranometer needs if the goal is to have the output of the DMM on a millivolt (mV) scale provide insolation readings directly in Btu/ft^2/h (full sun = 1 kW/m^2 = 317 Btu/ft^2/h = 317 mV).

Sketch the *I–V* curve with your load resistance superimposed onto it. Show the PV-curve at both 1-sun and 1/2-sun insolation.

b. Suppose you want the mV reading to be W/m^2. What resistance would work (but only for modest values of insolation). Draw an *I–V* curve with this resistor on it and make a crude estimate of the range of insolations for which it would be relatively accurate.

5.8 A 4-module array has two south-facing modules in series exposed to 1000 W/m^2 of insolation, and two west-facing modules exposed to 500 W/m^2. The 1-sun *I–V* curve for a single module with its MPP at 4A, 40 V is shown below.

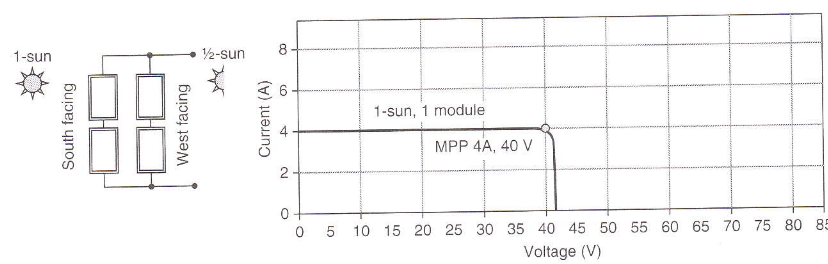

FIGURE P5.8

Draw the *I–V* curve for the 4-module array under these conditions. What is the output power (W) at the array's MPP?

5.9 A 200-W c-Si PV module has NOCT = 45°C and a temperature coefficient for rated power of −0.5%/°C.

a. At 1-sun of irradiation while the ambient is 25°C, estimate the cell temperature and output power.

b. Suppose the module is rigged with a heat exchanger that can cool the module while simultaneously providing solar water heating. How much power would be delivered if the module temperature is now 35°C? What percentage improvement is that?

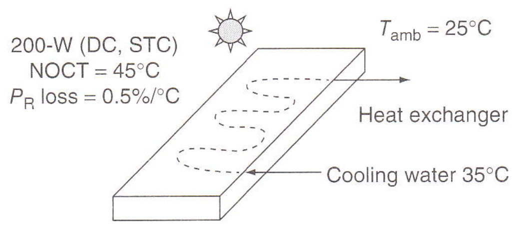

FIGURE P5.9

c. Suppose ambient is the same temperature, but now insolation drops to 0.8 kW/m^2. What percentage improvement in power output would the heat exchanger provide if it still maintains the cell temperature at 35°C?

5.10 Consider this very simple model for cells wired in series within a PV module. Those cells that are exposed to full sun deliver 0.5 V; those that are completely shaded act like 5-Ω resistors. For a module containing 40 such cells, an idealized *I–V* curve with all cells in full sun is as follows.

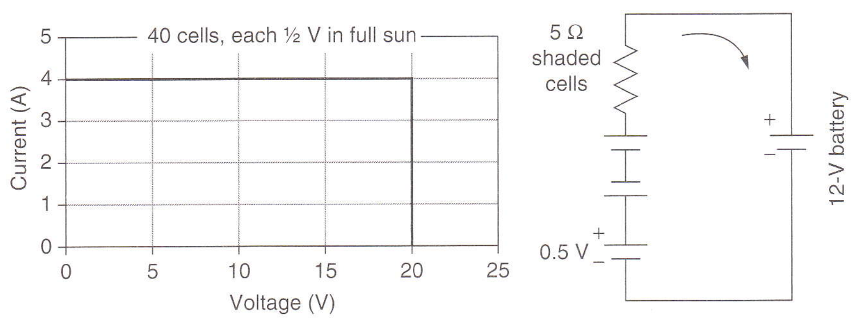

FIGURE P5.10

a. Draw the PV *I–V* curves that will result when one cell is shaded and when two cells are shaded (no battery load).

b. If you are charging an idealized 12-V battery (vertical *I–V* curve), compare the current delivered under these three circumstances (full sun and both shaded circumstances).

5.11 An idealized 1-sun I–V curve for a single 80-W module is shown below. For two such modules wired in series, draw the resulting I–V curve if the modules are exposed to only 1/2 sun, and one cell, in one of the modules, is shaded. Assume the shaded cell has an equivalent parallel resistance of 10 Ω.

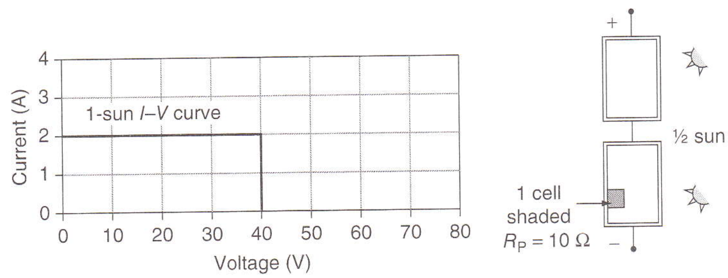

FIGURE P5.11

Sketch the resulting I–V curve. How much power would be generated at the MPP?

5.12 The 1-sun I–V curve for a 40-cell PV module in full sun is shown below along with an equivalent circuit for a single cell (including its 10 Ω parallel resistance).

An array with two such modules in series has one fully shaded cell in one of the modules. Consider the potential impact of bypass diodes around each of the modules.

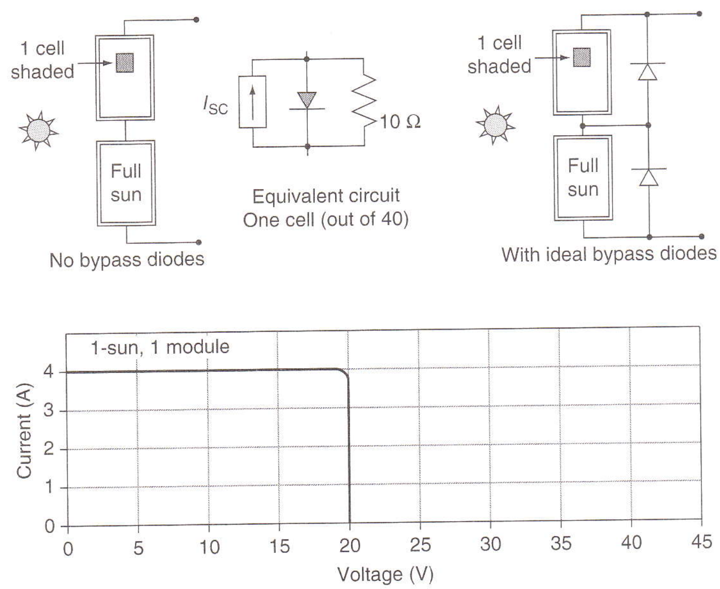

FIGURE P5.12

a. Sketch the 1-sun *I–V* curve for the series combination of modules with one cell shaded but no bypass diodes. Find the power output at the MPP. Compare it to the output when there is no shading.

b. Sketch the 1-sun *I–V* curve when the bypass diodes are included. Estimate the maximum power output now (close is good enough).

5.13 Consider a single 87.5 W, First Solar CdTe module (Table 5.3) used to charge a 12-V battery.

a. What duty cycle should be provided to an MPP, buck–boost converter to deliver 14 V to the battery when the module is working at standard test conditions? How many amperes will it deliver to the battery under those conditions?

b. Suppose ambient temperature is 25°C with 1-sun of insolation. Recalculate the amperes delivered to the battery.