To our teachers:

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Name: *______________________________

Date: *____ / ____ / ____ Class Hour: *____

	Wisconsin Public Service **SolarWise for Schools** and the **Center for Renewable Energy** **Advanced Technological Education**	

ENERGY STORAGE:
BATTERIES IN SERIES AND PARALLEL

INTRODUCTION:

While there are other kinds of energy storage, in this lesson we'll limit our study to the battery. A battery is a device that stores chemical energy and can convert it to usable electricity (the energy that results from the flow of electrons) in the form of direct current.

As you know, batteries are everywhere today, and their uses are being explored and expanded in more and more places. Batteries come to us in many shapes and sizes. But it's rare for an appliance to have a single battery cell custom made to power it. Usually appliance makers find a way to arrange several (or many) smaller, standard battery cells to satisfy their electrical requirements. We often call the resulting pack, or module, of battery cells "the battery" for its appliance or application.

Picture 1.	Picture 2.
	
Power tool battery pack made up of 15 separate lithium-ion battery	Electric vehicle battery pack made up of hundreds of lithium-ion battery cells. This is

cells. We usually call this pack, “the battery” for its power tool.	one of several battery modules that make up what we call “the battery” of an EV.

It should now be understood that what we often casually refer to as a battery, is really several (or many) smaller battery cells of a standard size wired together. But their wiring configuration is purposefully designed to provide the power and capacity needed to satisfy the requirements for the battery application.

What are these wiring configurations? What are the principles that guide and govern their use? That’s what you’ll determine in this lesson. By the time you’re finished with this lab exercise you’ll understand these principles and be able to make accurate predictions of battery power and capacity from them.

Let’s start here.

Question 1a. Write down your teacher’s definition of a circuit wired in series, or research one that you understand well.

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____

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Question 1b. Write down your teacher’s definition of a circuit wired in parallel, or research one that you understand well.

____

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Materials, Resources, and Technology Required:

- 12 fully charged rechargeable batteries
- 12 battery holders with pin contact extensions
- 3 wood battery holder holders
- Numerous alligator clip colored wires
- 6 V incandescent bulb with screw in base
- 1 Telegraph key circuit connector switch

- 1 Multimeter

Procedure:

In the first part of this lesson you'll take lab measurements on batteries of two different types wired in different configurations. A PowerPoint has been prepared to guide you through how to do the wiring. Your measurements will be taken from standard AA rechargeable batteries in a variety of configurations.

Once your lab work is finished, you'll complete a succession of **Summary Questions** designed to reinforce and extend what you learned in the lab.

1. Follow the PowerPoint from the start, one lab setting at a time.

2. Identify the wiring configuration in the photo. Write its abbreviation into your data table if it's been left blank.

3. Wire your battery/batteries, load, telegraph key switch, and multimeter (set to record DC Volts) to correspond to the wiring configuration. Your wires will probably not match the colors in the photos. It may be helpful, but it's not necessary for you to perfectly match the way we've organized our wiring. You may use any color scheme you prefer so long as it's organized and corresponds to the correct configuration for each slide.

4. Predict the electrical potential in Volts you expect to achieve when you complete the circuit by pressing the telegraph key switch. Write it into your data table. You should have some basis for predicting the Volts for each setting if you read the entire lab activity, are observant, and apply what you learn in each lab setting.

5. Complete the circuit by pressing the telegraph key switch. Record the Volts measurement observed on the multimeter in your data table.

6. STOP! Compare the measured result to your prediction. If they match, explain why. If they don't match, explain why. Ask questions of your teacher as needed. Discuss the principles of battery behavior you're observing.

7. Move on to the next lab setting in the PowerPoint. Repeat these steps until you're finished with the lab.

Following are wiring configuration abbreviations you'll need to interpret and use, and what they mean:

1 B: One battery wired to a load.
2 S: Two batteries wired in series.
2 P: Two batteries wired in parallel.
2P2S: Two parallel strings of two batteries in series. Alt text explanations

Begin by wiring the battery configuration labeled **Lab Setting 1** in your PowerPoint.

Table 1. Rechargeable Battery Measurements

Lab Setting:	Wiring Configuration:	Electrical Potential (Volts) **Prediction:**	Electrical Potential (Volts) **Measurement:**
1.	**1B**	*	*
2.	**2S**	*	*
3.	*	*	*
4.	*	*	*
5.	**1B**	*	*
6.	**2P**	*	*
7.	*	*	*
8.	*	*	*
9.	**2P2S**	*	*
10.	*	*	*
11.	*	*	*
12.	*	*	*
13.	*	*	*
14.	*	*	*

Lesson Summary Questions

Question 2a. Using what you've just learned, write a clear general statement that explains what happens with electrical potential (Volts) when batteries are configured (wired) in a series circuit.

____

____

____

Question 2b. Using what you've just learned, write a clear general statement that explains what happens with electrical potential (Volts) when batteries are configured (wired) in a parallel circuit.

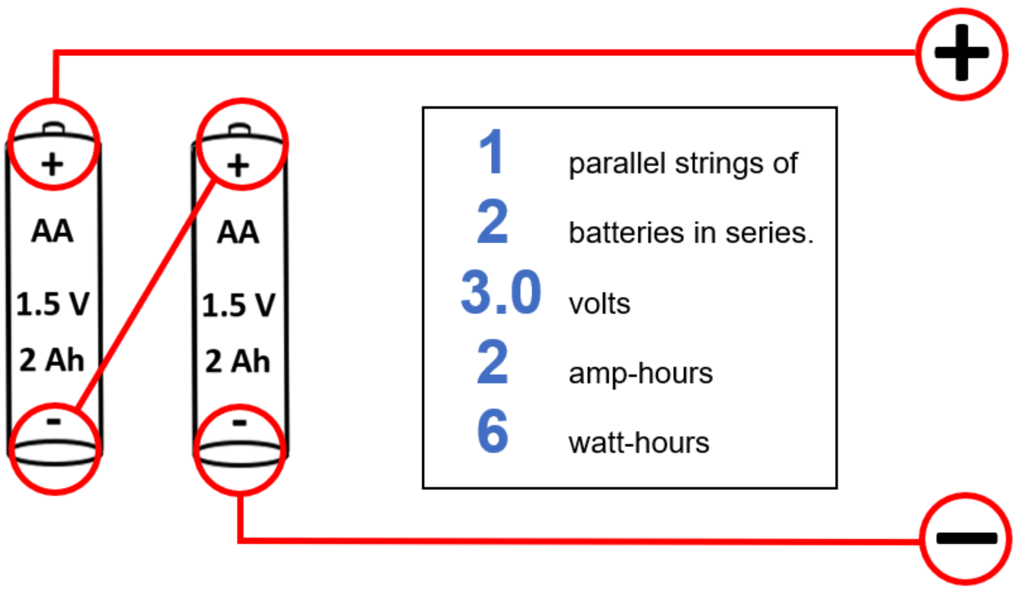
____

____

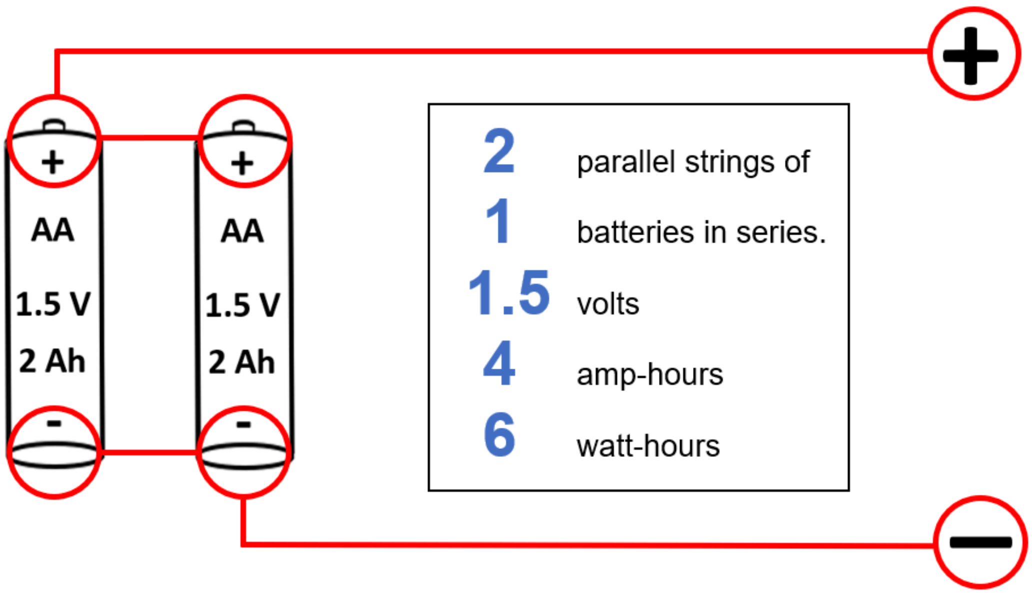
____

On this page and the next are sample battery wiring diagrams. The first three diagrams are examples in basic series and parallel configurations. Consider what you've learned in this lesson and what you learn by looking at our examples. Then fill in information for each of the numbered wiring diagram questions that follow.

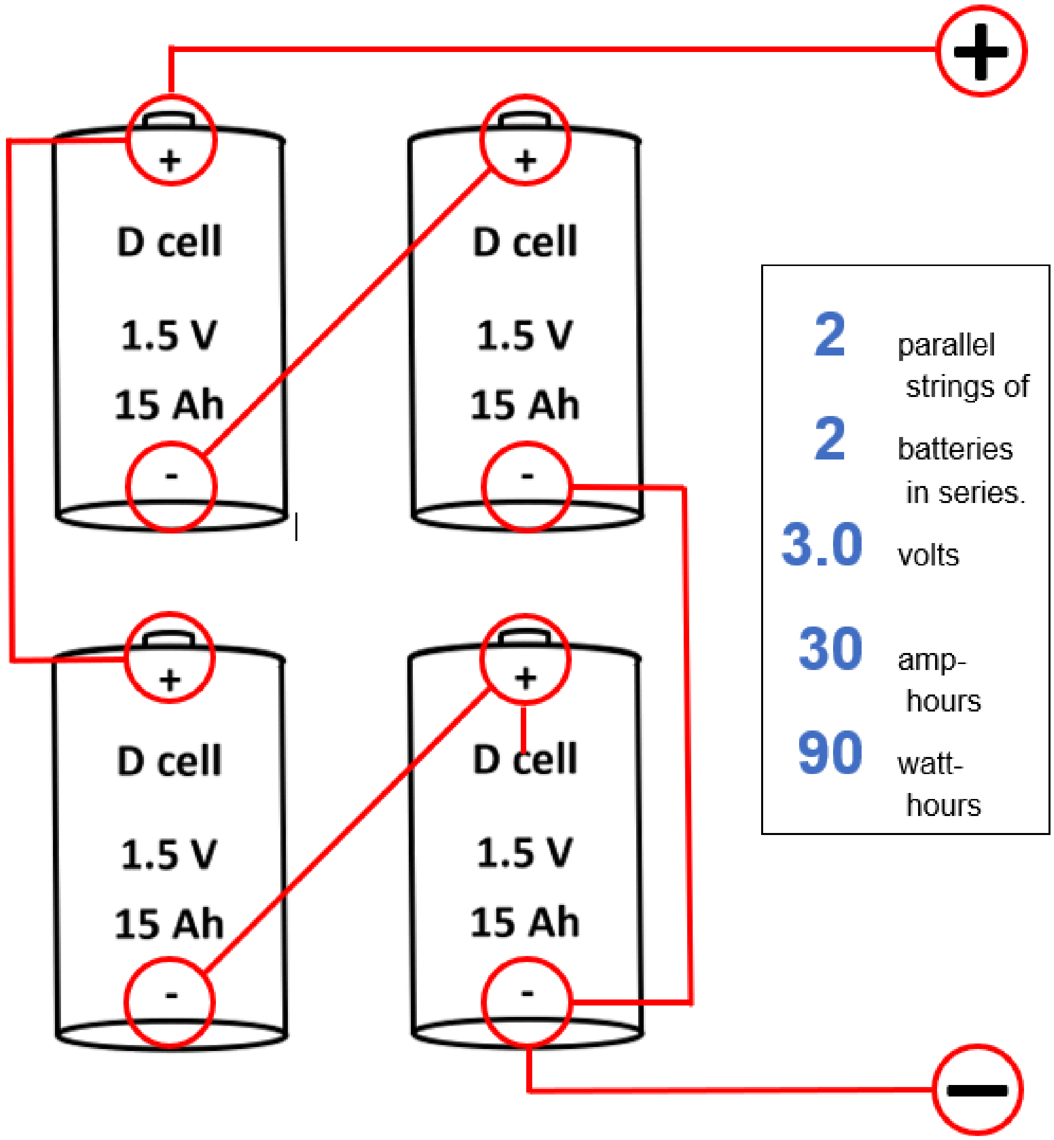
Example I.



Example II.

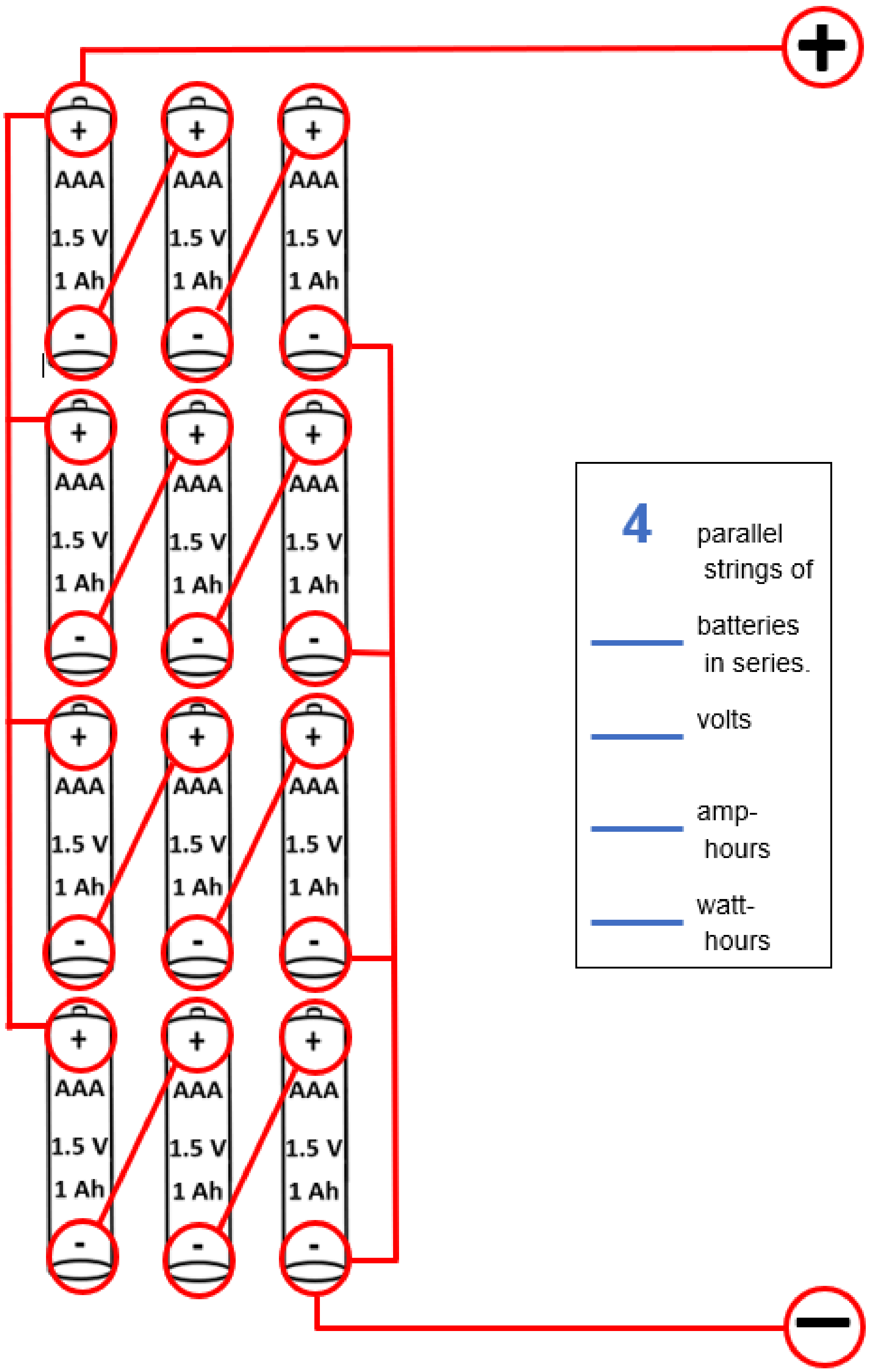

AA
1.5 V
2 Ah
AA
1.5 V
2 Ah
2 parallel strings of
1 batteries in series.
1.5 volts
4 amp-hours
6 watt-hours

Example III.

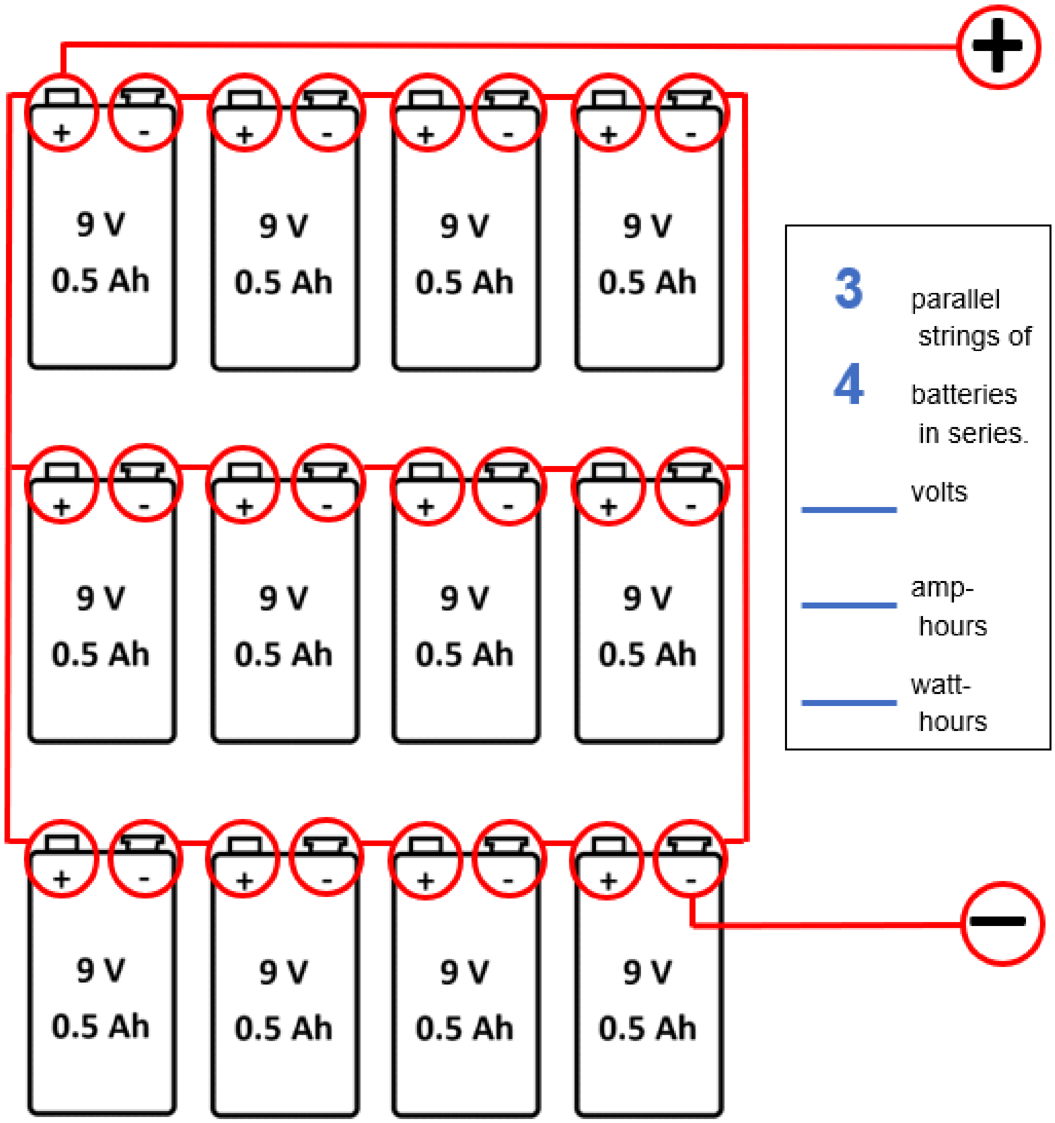


Common household single use, disposable batteries:

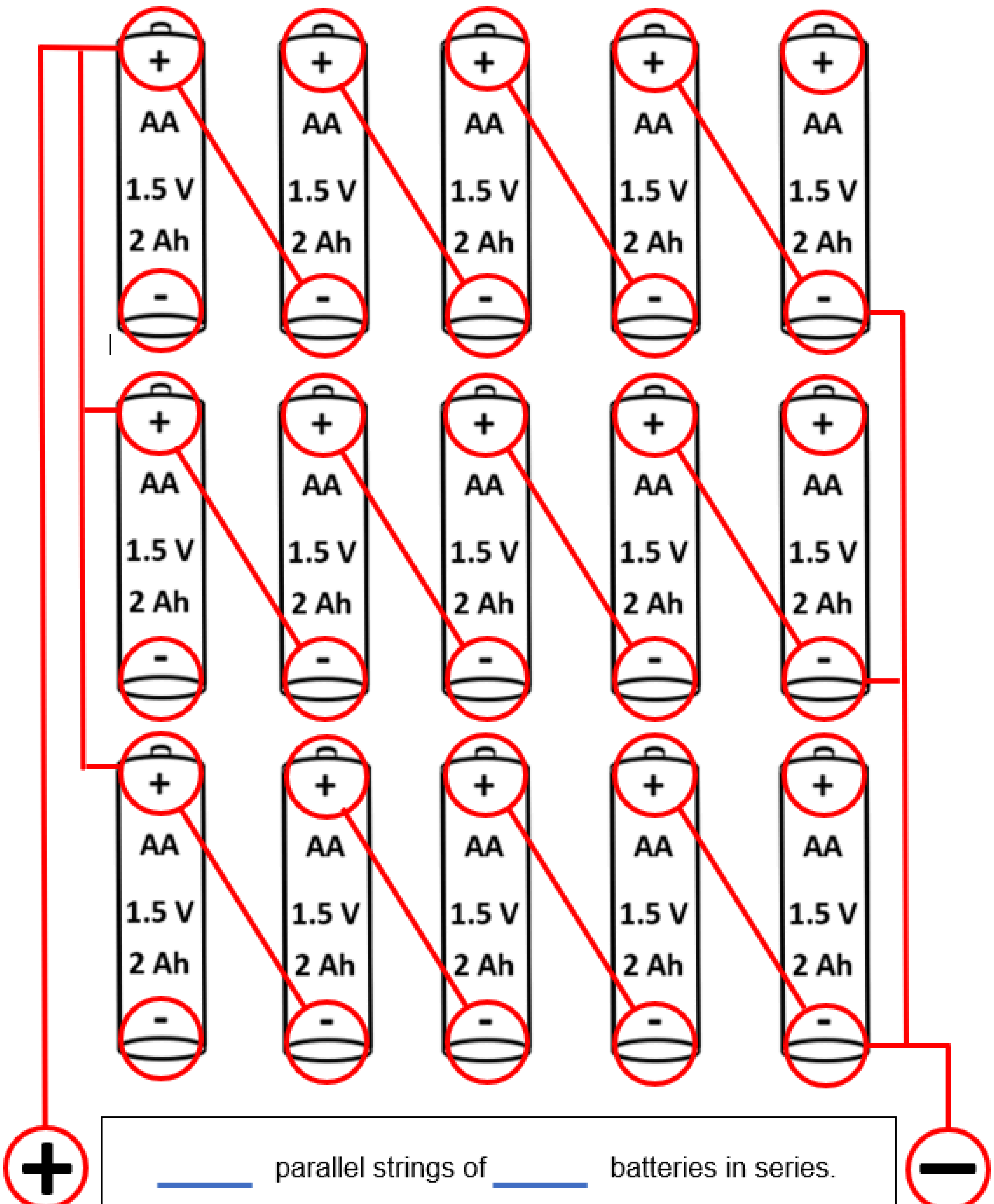
Question 3.


+
AAA
1.5 V
1 Ah
-
4
parallel strings of
batteries in series.
volts
amp-hours
watt-hours

Question 4.


9 V
0.5 Ah
9 V
0.5 Ah
9 V
0.5 Ah
9 V
0.5 Ah
9 V
0.5 Ah
9 V
0.5 Ah
9 V
0.5 Ah
9 V
0.5 Ah
9 V
0.5 Ah
9 V
0.5 Ah
9 V
0.5 Ah
9 V
0.5 Ah
3 parallel strings of
4 batteries in series.
_____ volts
_____ amp-hours
_____ watt-hours

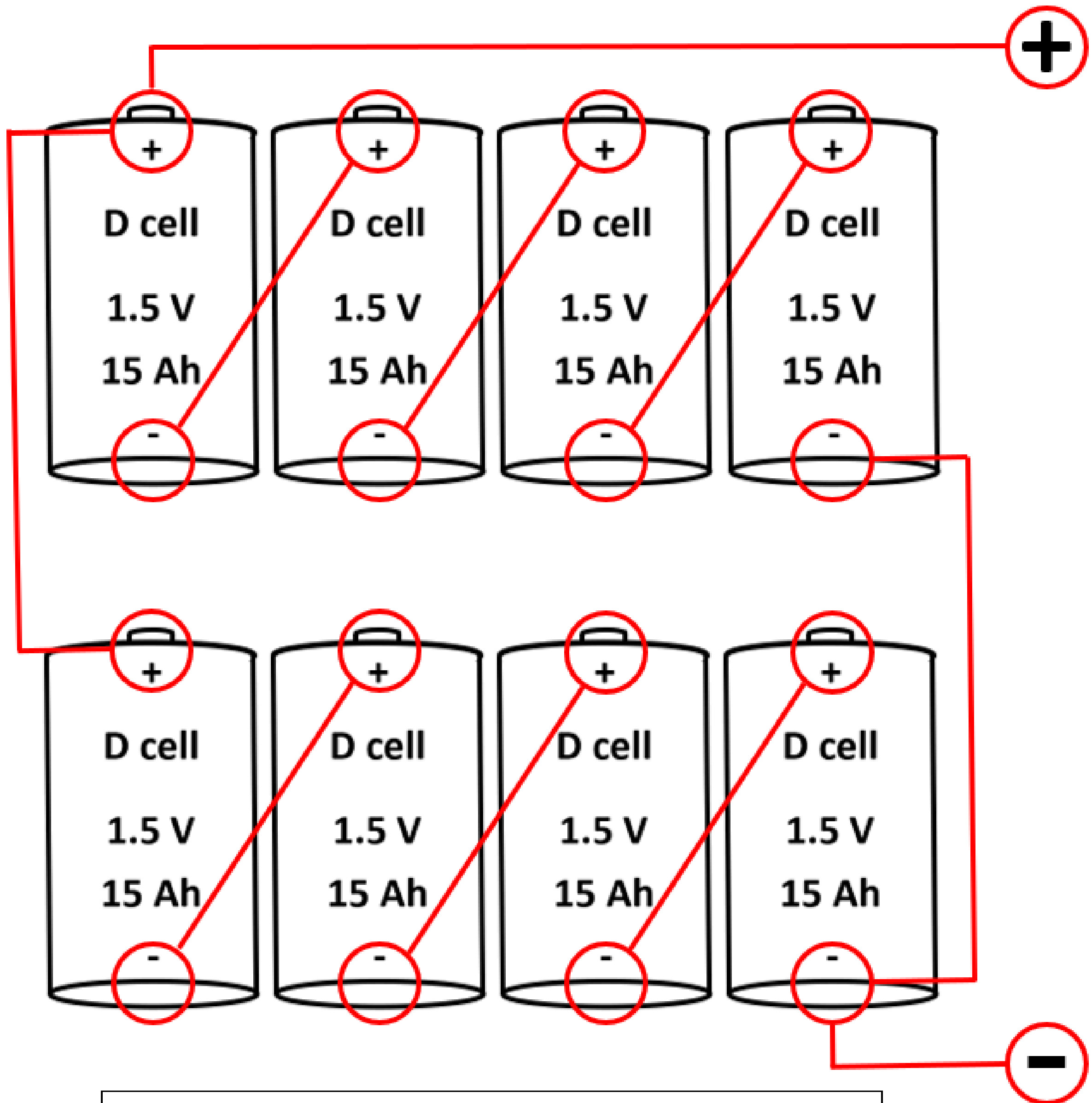
Question 5.



______ parallel strings of ______ batteries in series.

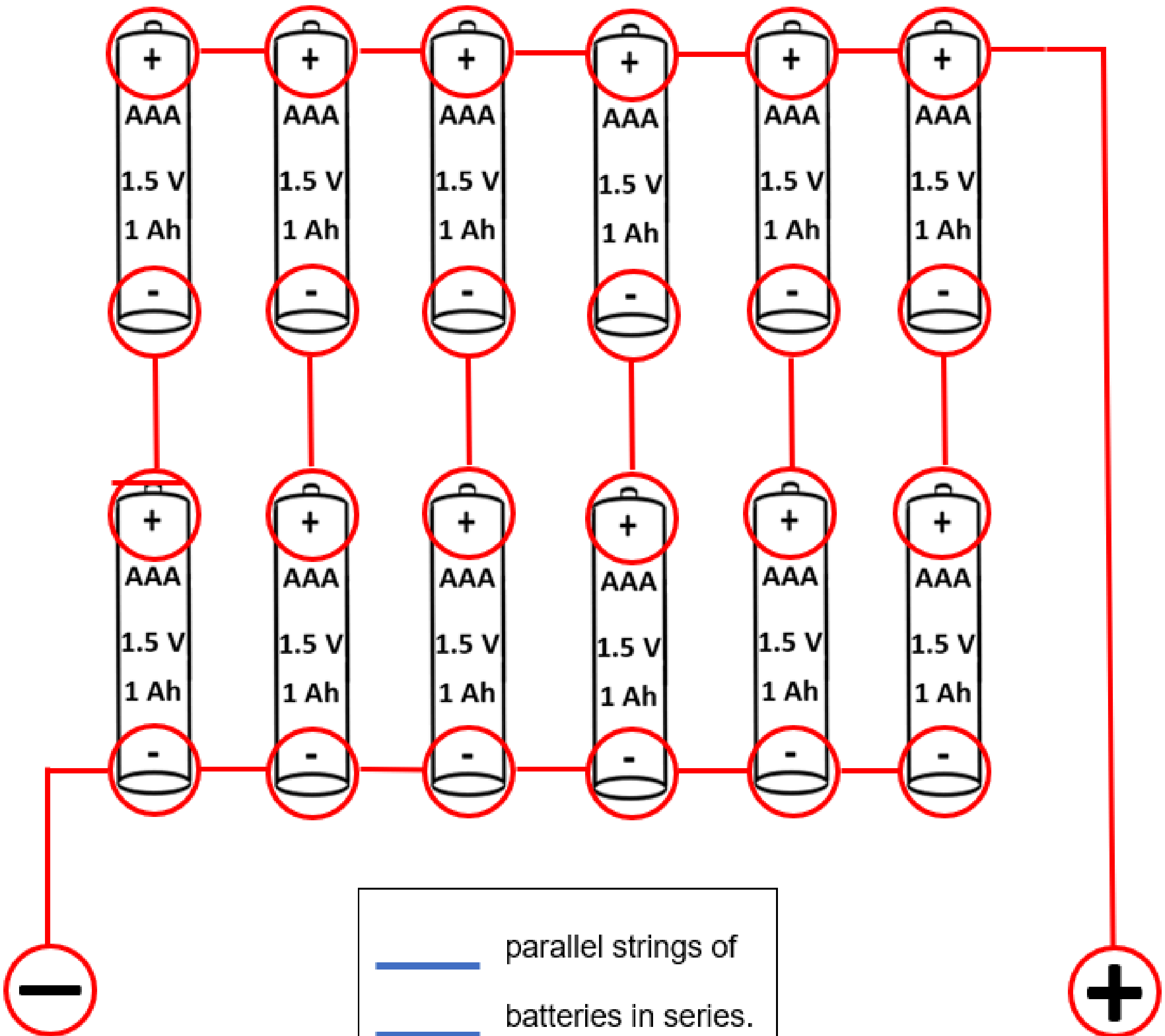
______ volts ______ amp-hours ______ watt-hours

Question 6.



______	parallel strings of	______	batteries in series.		
______	volts	______	amp-hours	______	watt-hours

Question 7.



______ parallel strings of

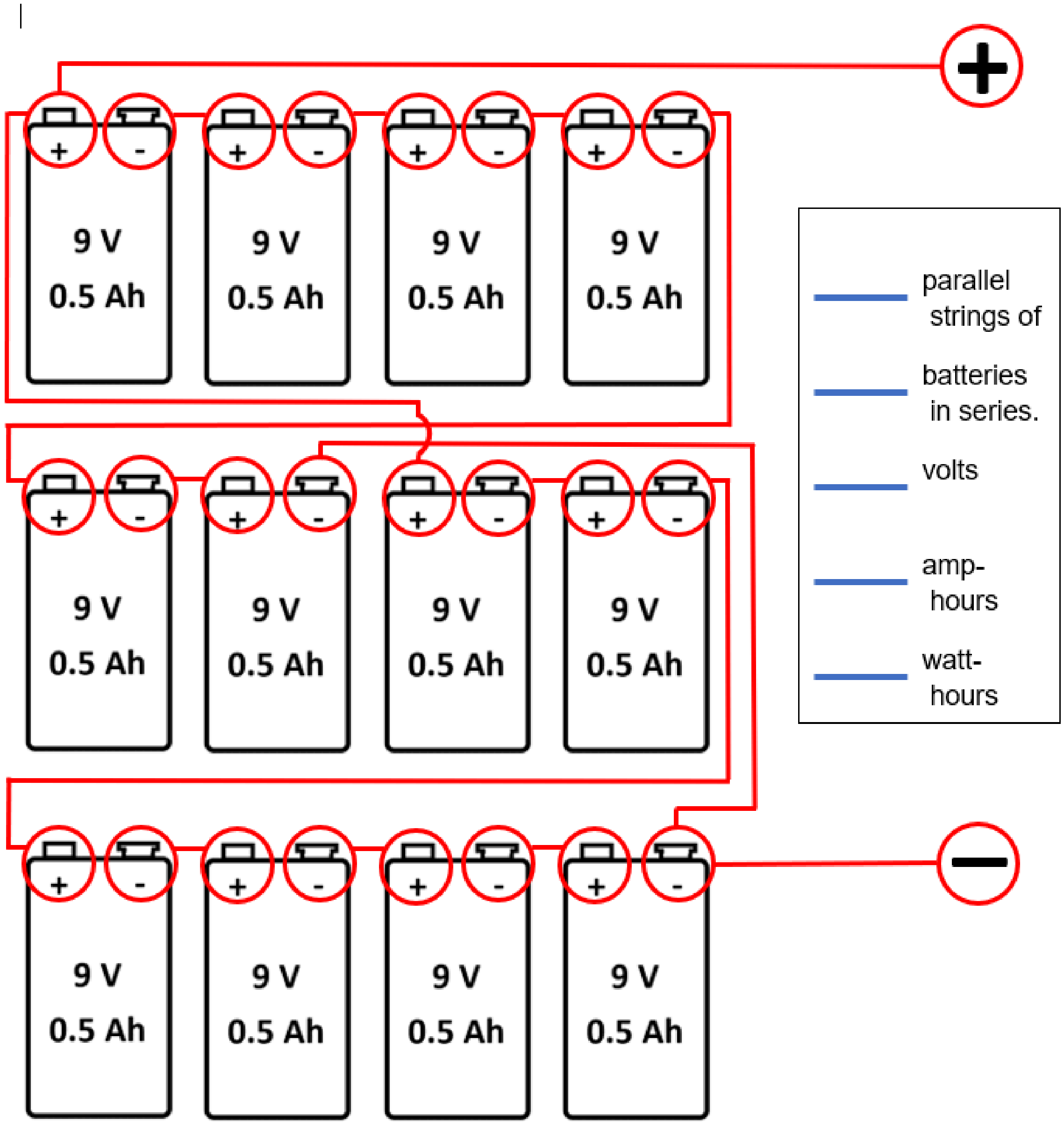
______ batteries in series.

______ volts

______ amp-hours

______ watt-hours

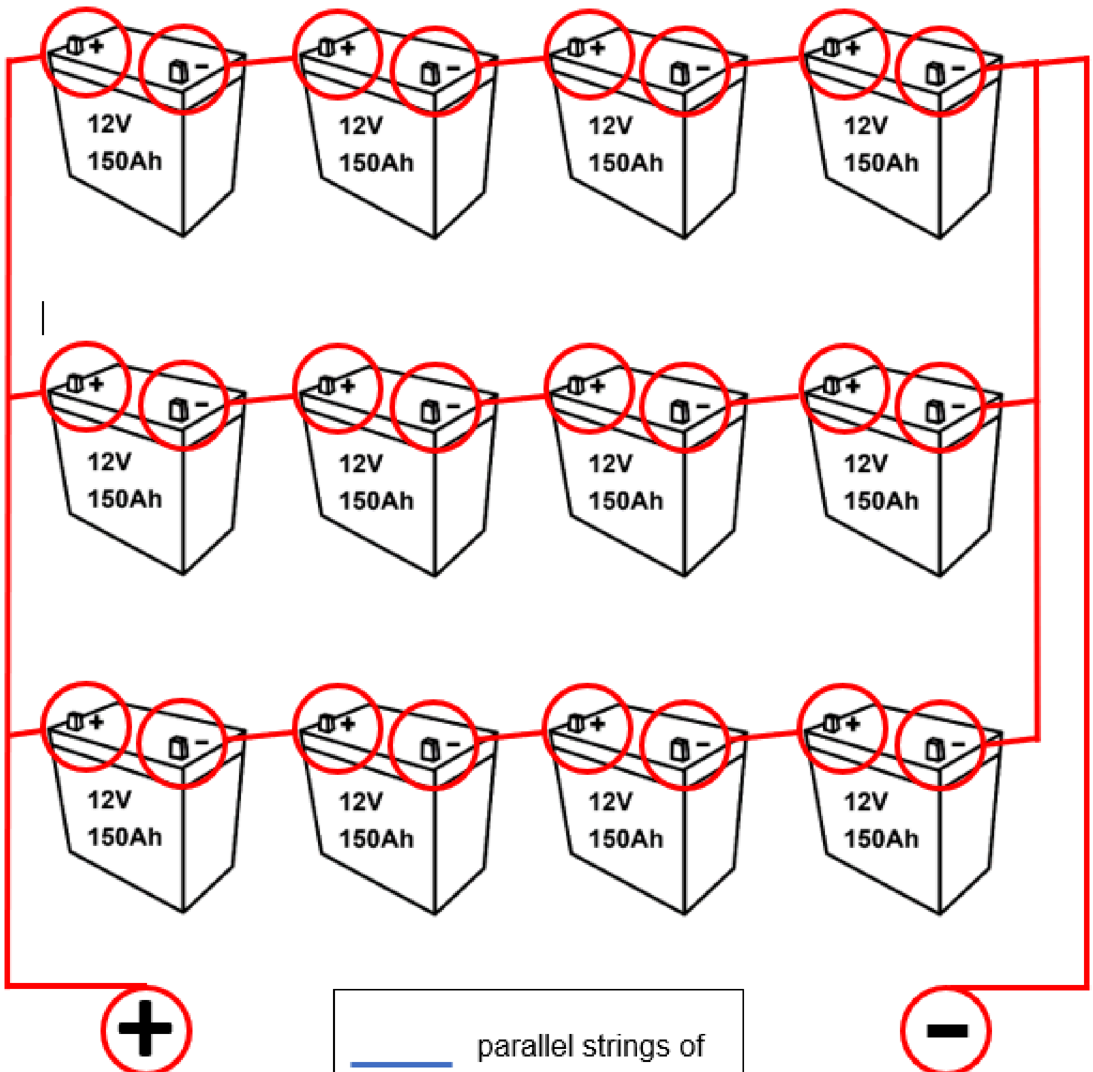
Question 8.



+
-
9 V
0.5 Ah
parallel strings of
batteries in series.
volts
amp-hours
watt-hours

Lead-acid batteries, formerly the first choice for solar PV energy storage:

Question 9.



______ parallel strings of

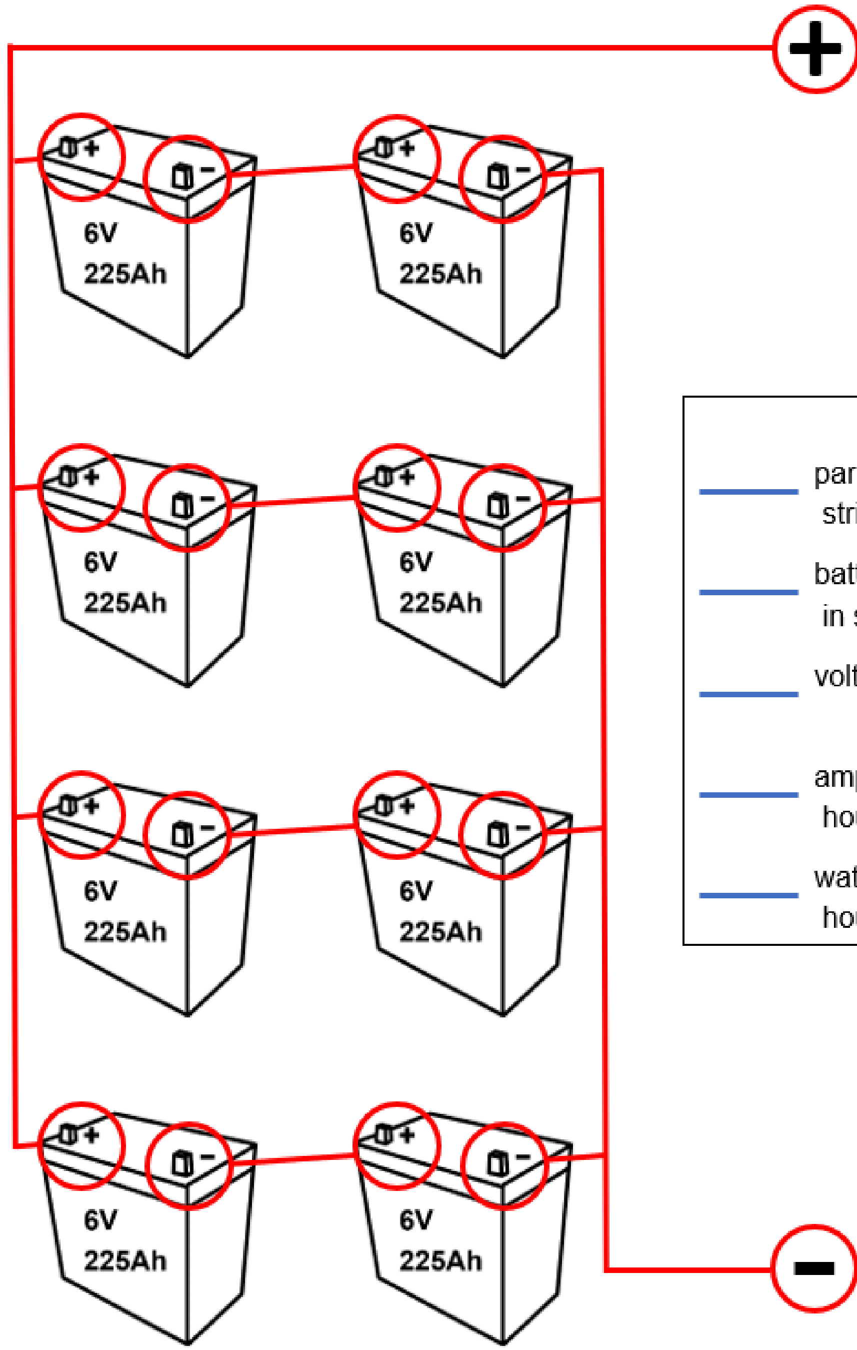
______ batteries in series.

______ volts

______ amp-hours

______ watt-hours

Question 10.



______ parallel strings of

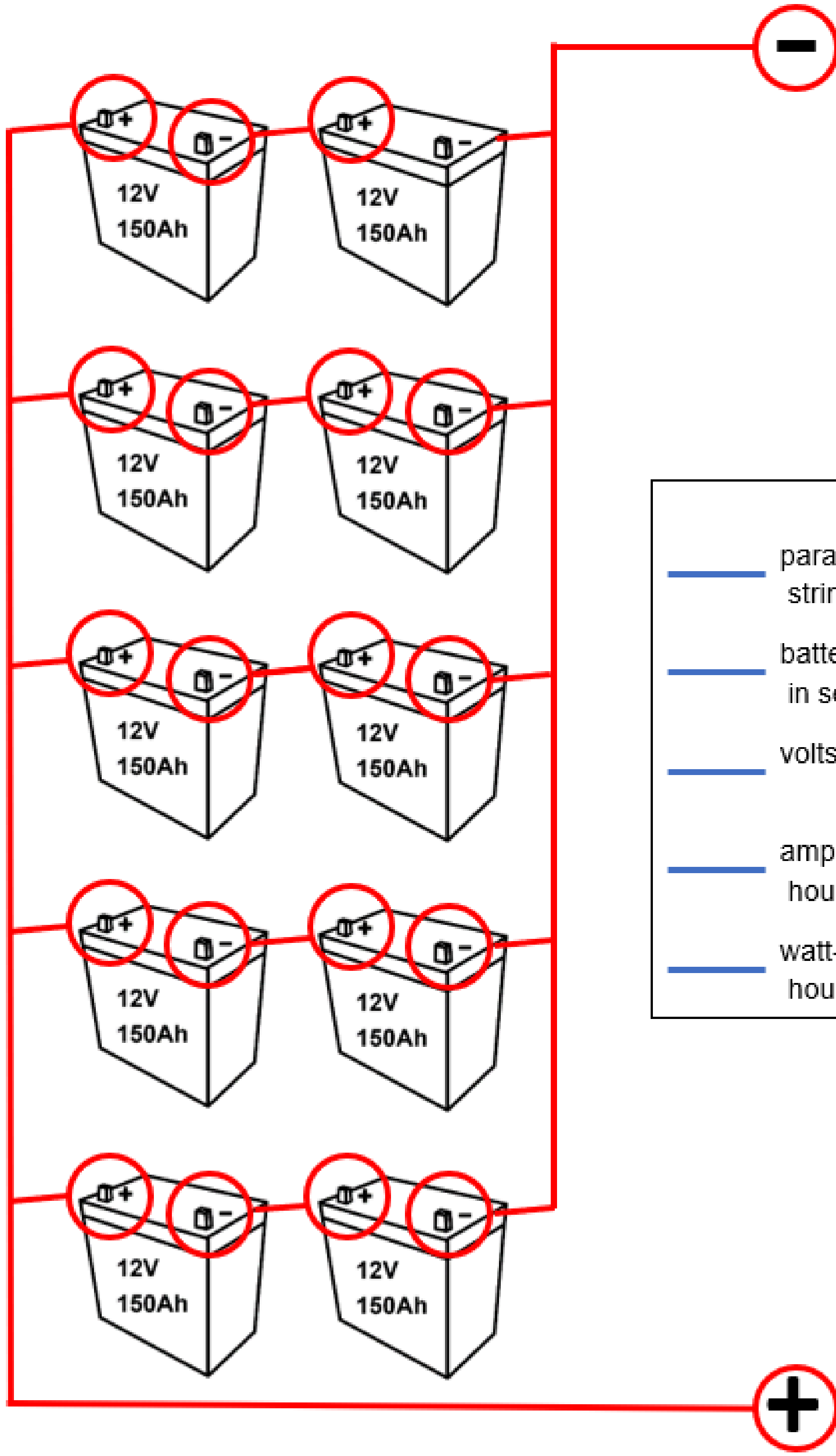
______ batteries in series.

______ volts

______ amp-hours

______ watt-hours

Question 11.



________ parallel strings of

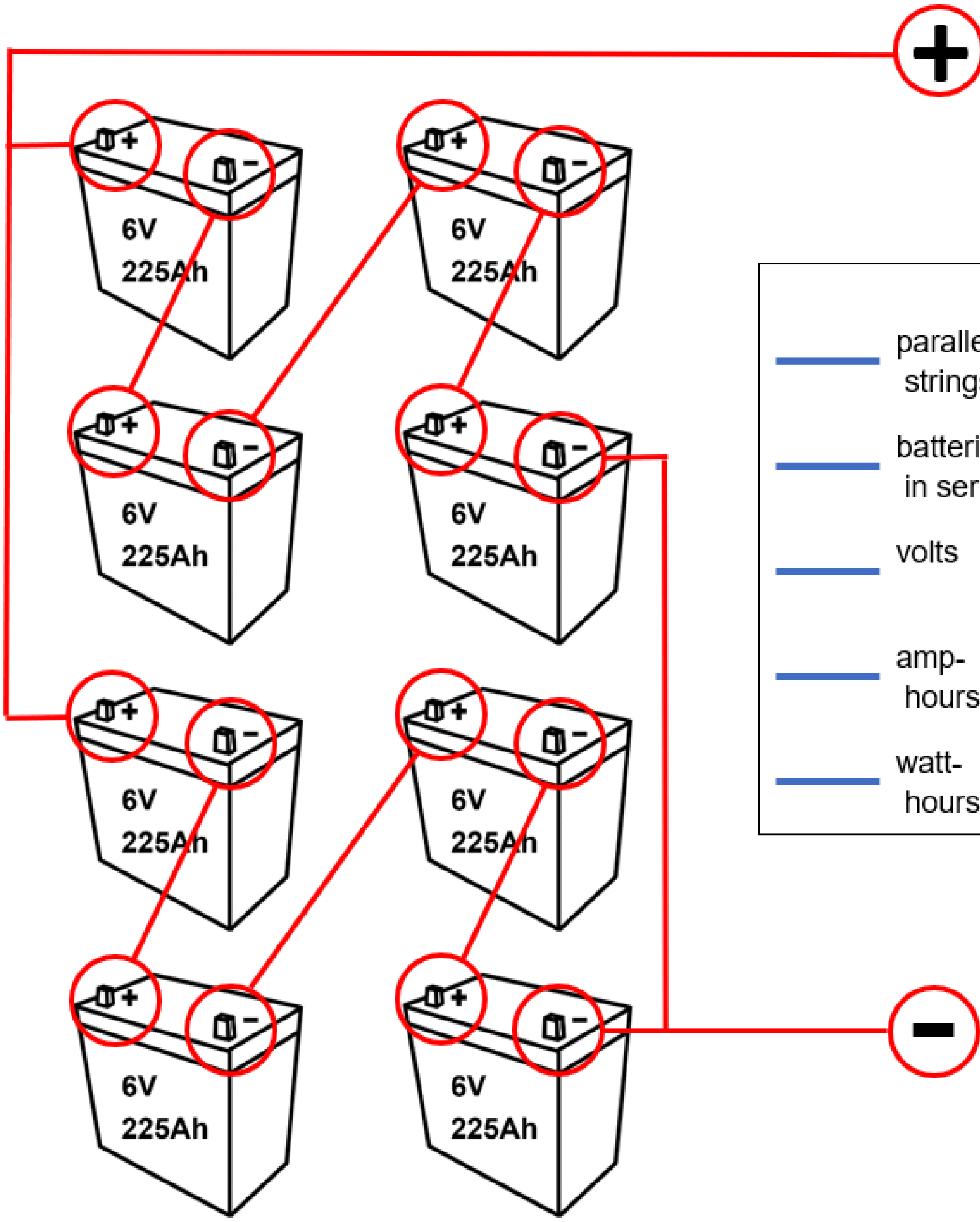
________ batteries in series.

________ volts

________ amp-hours

________ watt-hours

Question 12:



_____ parallel strings of

_____ batteries in series.

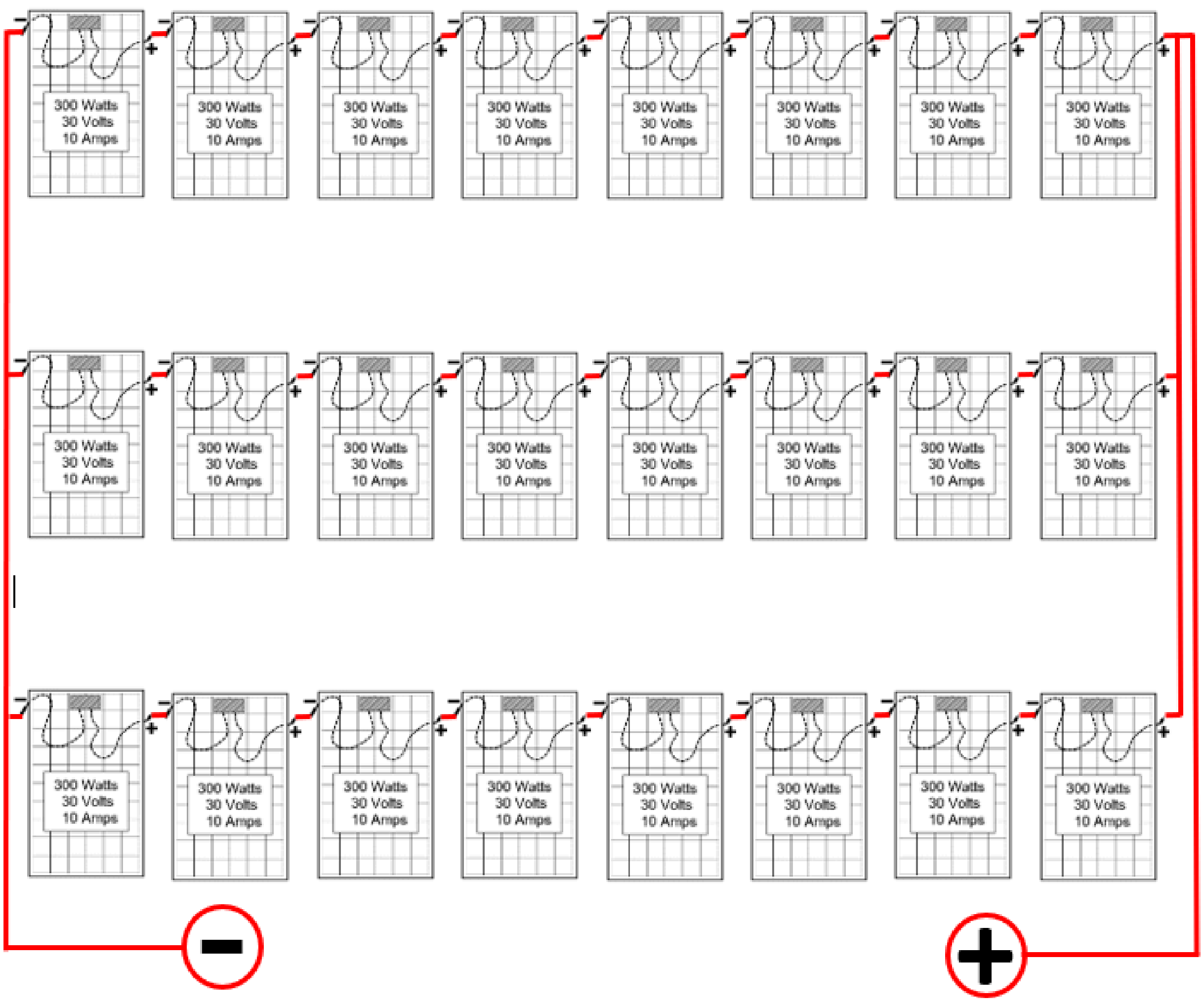
_____ volts

_____ amp-hours

_____ watt-hours

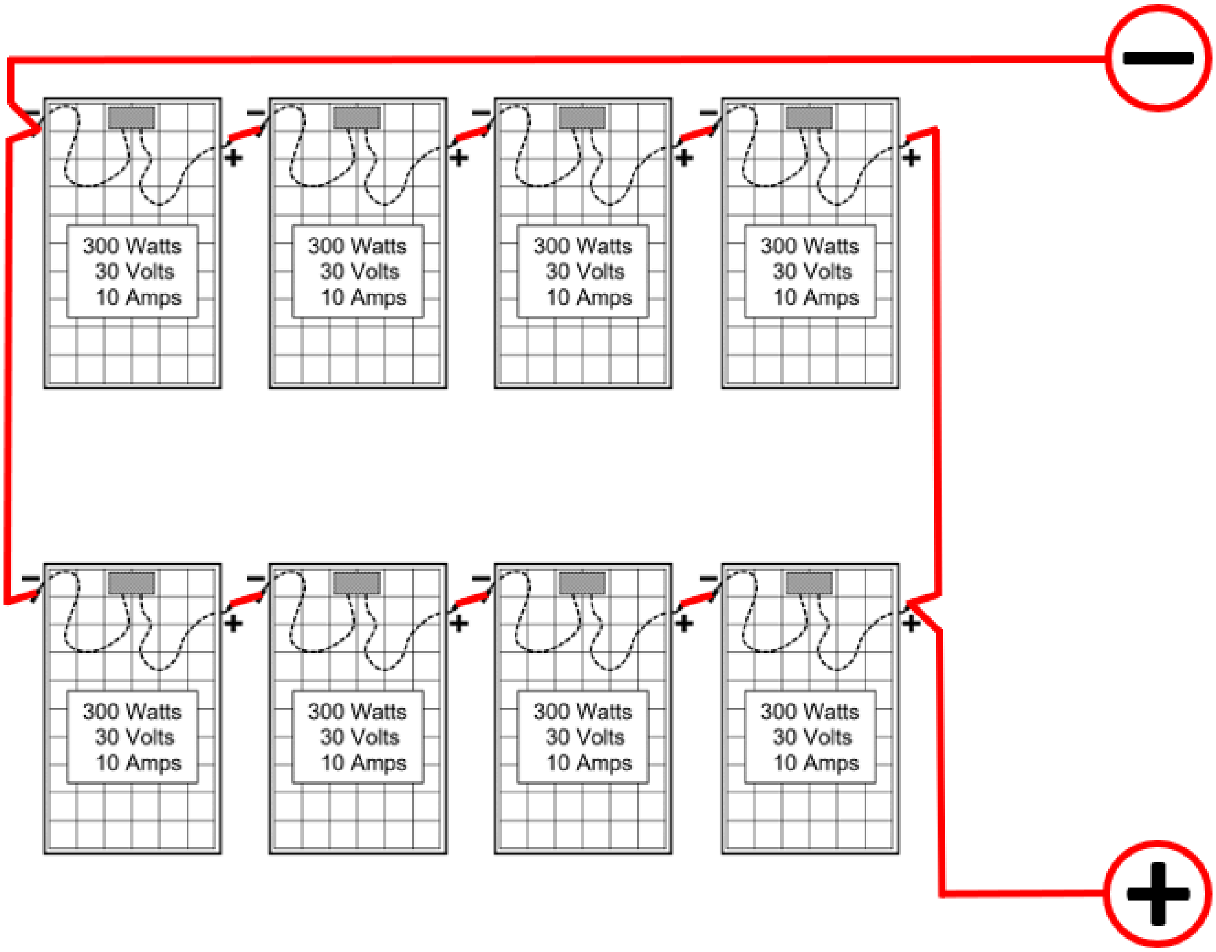
Solar PV modules connected with a string inverter follow principles very similar to batteries:

Example IV.



3 parallel strings of		**8**	modules in series.	
240 volts		**30** amps		**7200** watts

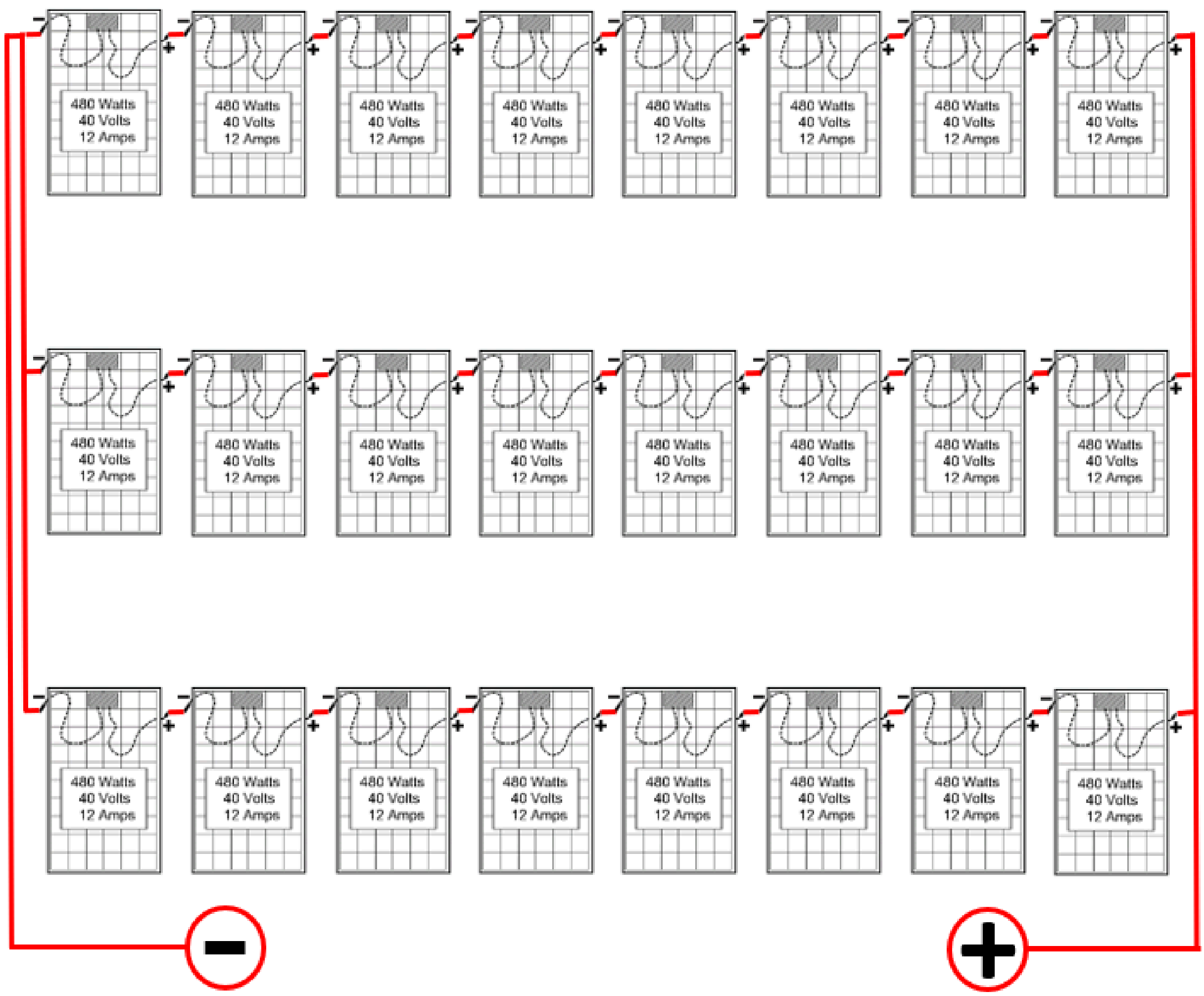
Question 13:



______ parallel strings of ______ modules in series.

______ volts ______ amps ______ watts

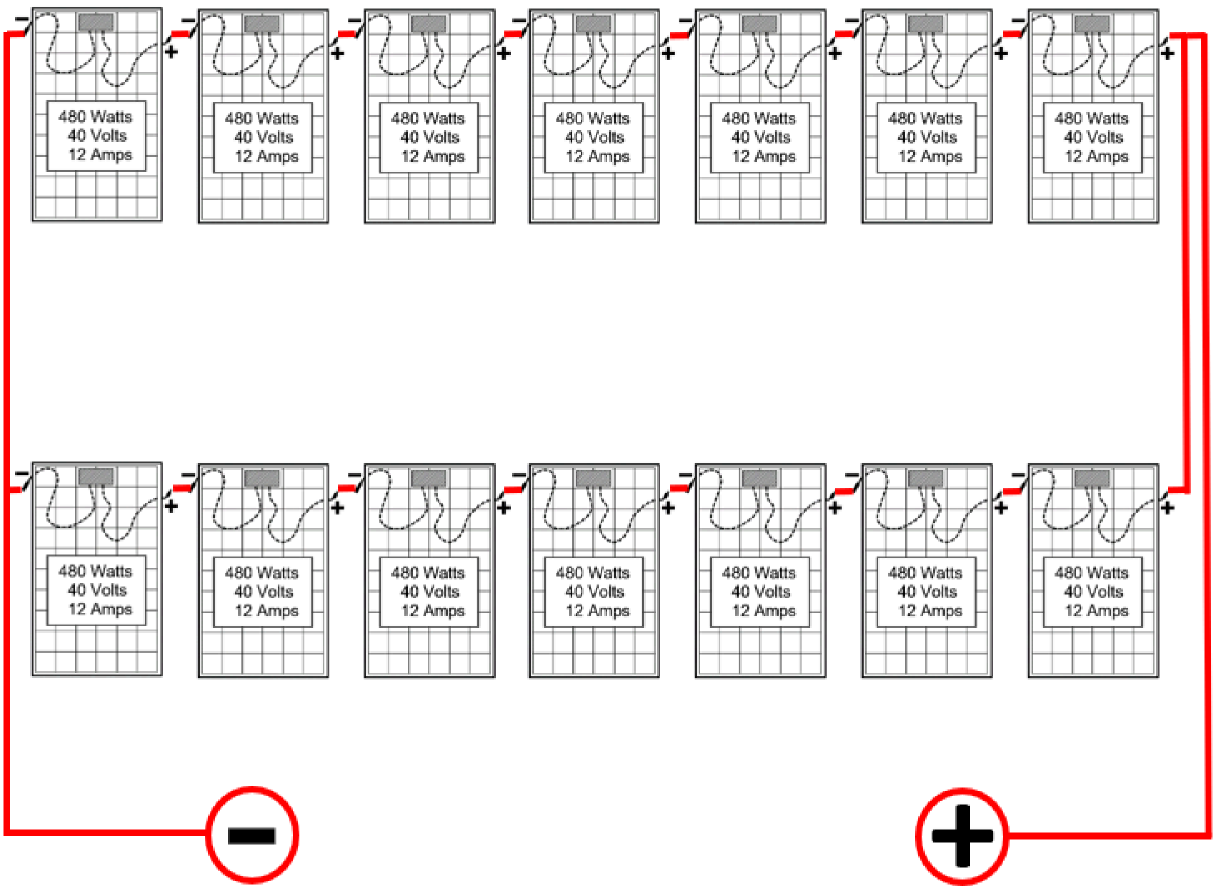
Question 14:



_____ parallel strings of _____ modules in series.

_____ volts _____ amps _____ watts

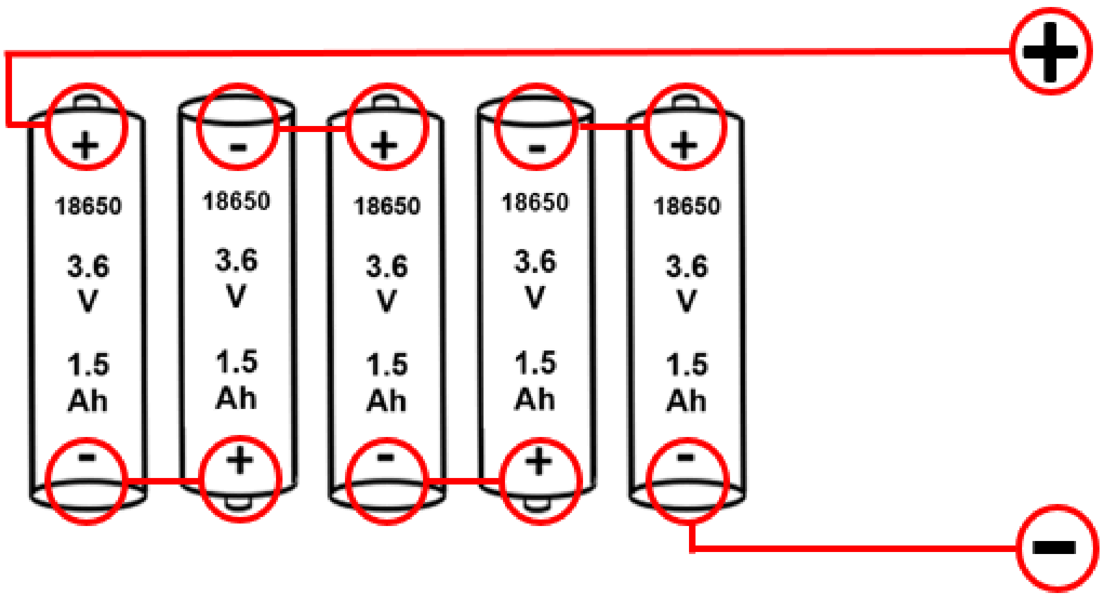
Question 15:



______	parallel strings of	______	modules in series.		
______	volts	______	amps	______	watts

Rechargeable Lithium Ion Batteries:

Question 16:



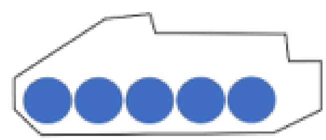
______ parallel strings of

______ batteries in series.

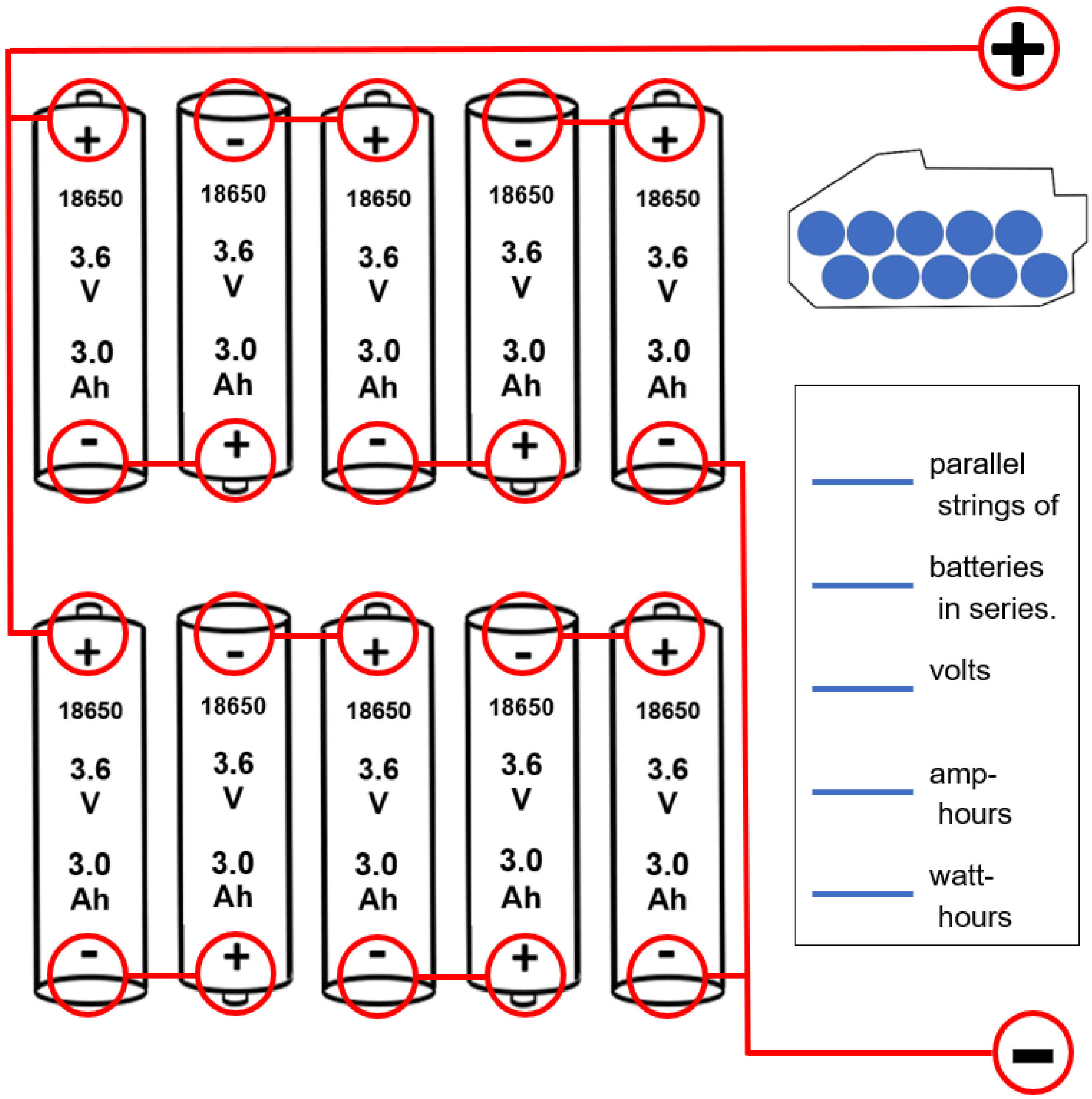
______ volts

______ amp-hours

______ watt-hours



Question 17:



_____ parallel strings of

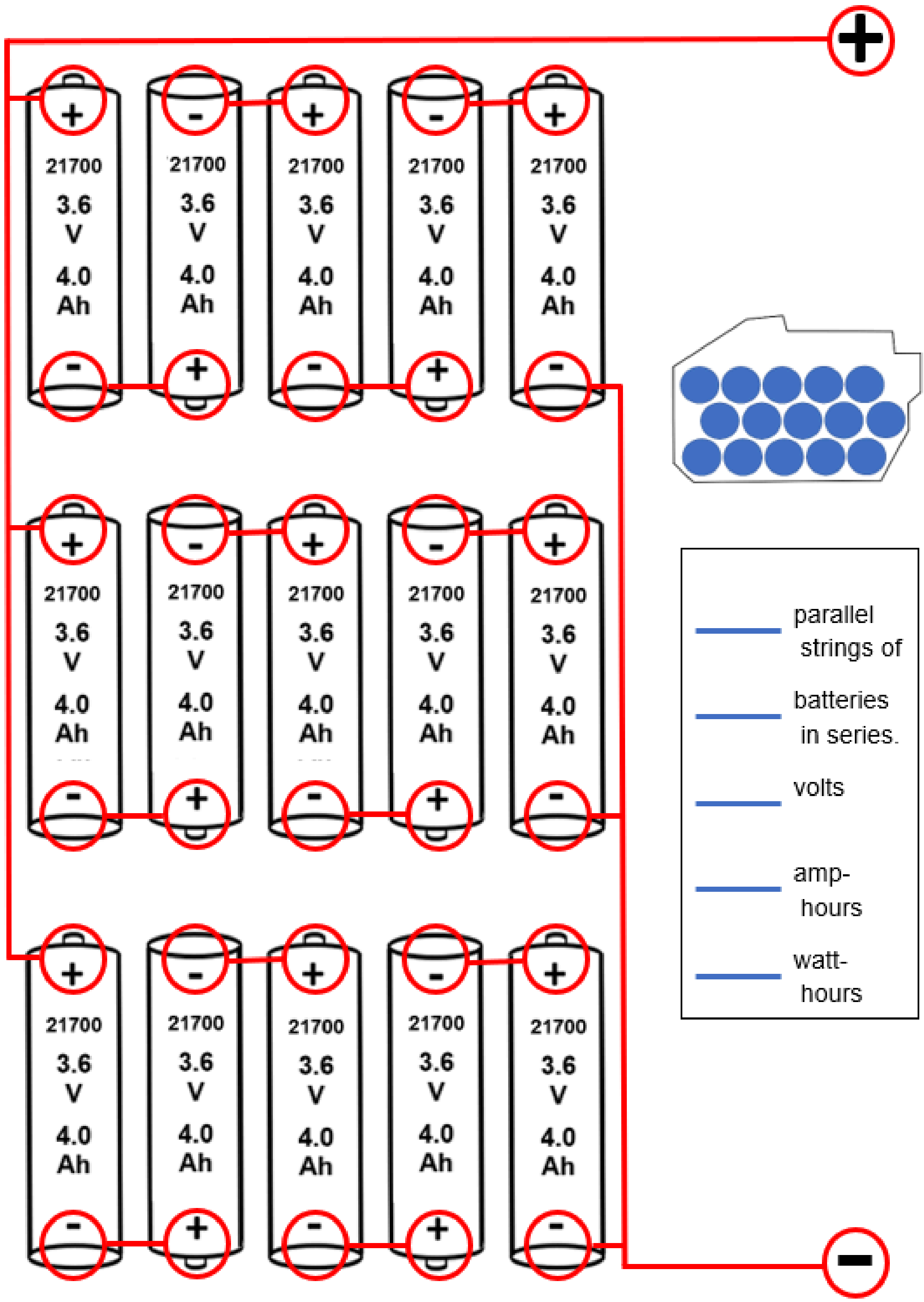
_____ batteries in series.

_____ volts

_____ amp-hours

_____ watt-hours

Question 18:



____ parallel strings of

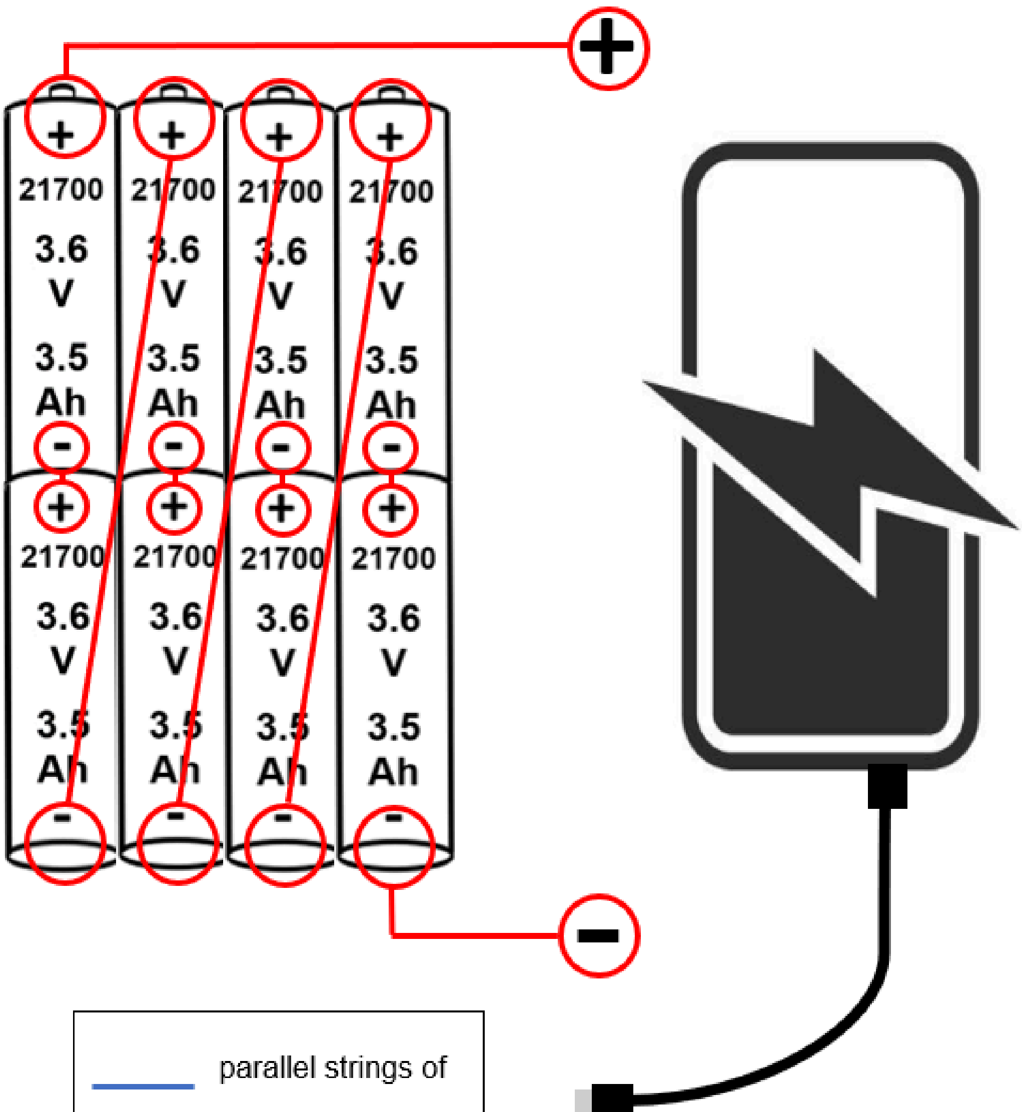
____ batteries in series.

____ volts

____ amp-hours

____ watt-hours

Question 19:



_____ parallel strings of

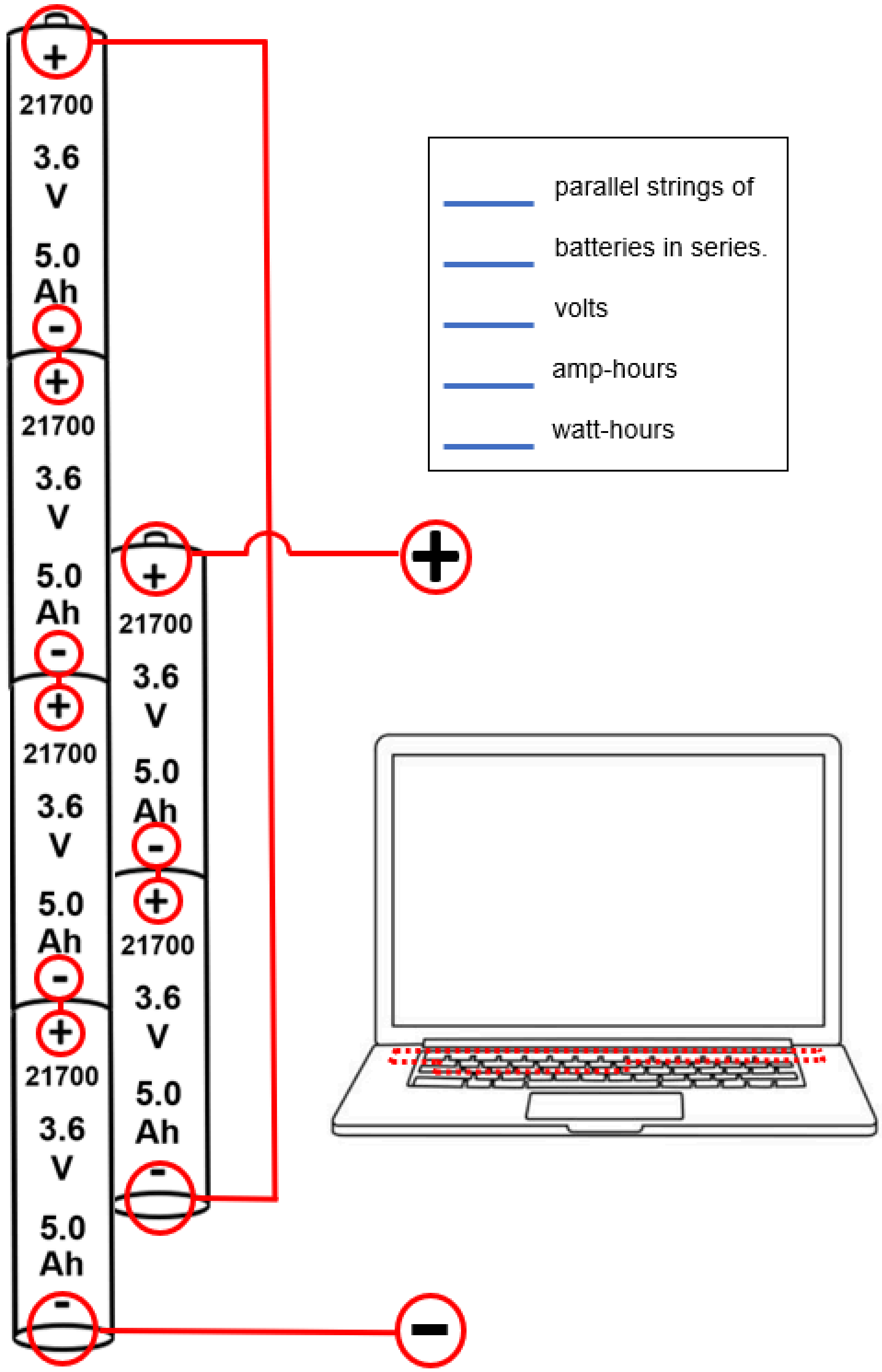
_____ batteries in series.

_____ volts

_____ amp-hours

_____ watt-hours

Question 20:



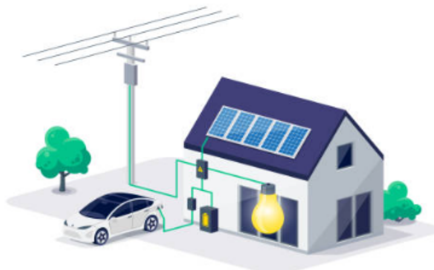
________ parallel strings of

________ batteries in series.

________ volts

________ amp-hours

________ watt-hours



Question 21. Most modern solar PV storage systems now employ lithium ion battery technology. The individual battery cell used in one of those systems is called an LFP Prismatic cell. Here are the specifications for one particular LFP cell:

- 3.2 Volts (nominal)
- 200 Amp-hours

The “battery pack” for a certain solar PV storage system is made up of 15 of these cells with a battery management system configured this way:

- 1 parallel string of 15 cells wired in series (1 P, 15 S)

21a. From the information above, calculate the Volts, Amp-hours, and kilowatt-hours for the solar PV battery pack.

______ **Volts**
______ **Amp-hours**
______ **kilowatt-hours**

This battery pack may have enough capacity to satisfy the solar PV electrical storage needs of many homeowners.

Imagine you are a homeowner wanting additional storage capacity. However, you don’t want your PV storage system to exceed 50 Volts. There are good reasons for the 50 Volt limit that won’t be discussed here. For this reason, you buy a second battery pack, wiring your two packs in parallel. Here is how they are configured:

- 2 parallel strings of 15 cells wired in series (2 P, 15 S)

21b. From the information above, calculate the Volts, Amp-hours, and kilowatt-hours for your enlarged solar PV battery system.

______ **Volts**
______ **Amp-hours**

_____ **kilowatt-hours**

Question 22. The battery for an electric vehicle is made up of individual battery cells, scaled up and wired to provide the necessary electrical storage capacity and power. One vehicle may have thousands of cells on board. Individual battery cells are usually assembled and wired into larger modules. Then several modules are assembled and wired together to produce the entire battery for the EV.

Imagine the individual battery cell used in a certain EV has these specifications:

- 3.7 Volts (nominal)
- 3.0 Amp-hours

864 of the cells make up a battery module (sometimes called a sub-module), each with its own battery management system. The individual cells are configured this way:

- 72 parallel strings of 12 cells wired in series (72 P, 12 S)

22a. From the information above, calculate the Volts, Amp-hours, and kilowatt-hours for one EV module.

_____ **Volts**
_____ **Amp-hours**
_____ **kilowatt-hours**

Nine (9) of these modules are then wired together in series for placement into the EV.

22b. From this information, calculate the Volts, Amp-hours, and kilowatt-hours for the entire EV battery.

_____ **Volts**
_____ **Amp-hours**
_____ **kilowatt-hours**

Question 23a. Consider what you just learned in completing Lesson Summary Questions 3-22. Write a clear general statement that explains what happens with battery capacity (Amp-hours) when batteries are configured (wired) in a series circuit.

Question 23b. Consider what you just learned in completing Lesson Summary Questions 3-22. Write a clear general statement that explains what happens with battery capacity (Amp-hours) when batteries are configured (wired) in a parallel circuit.