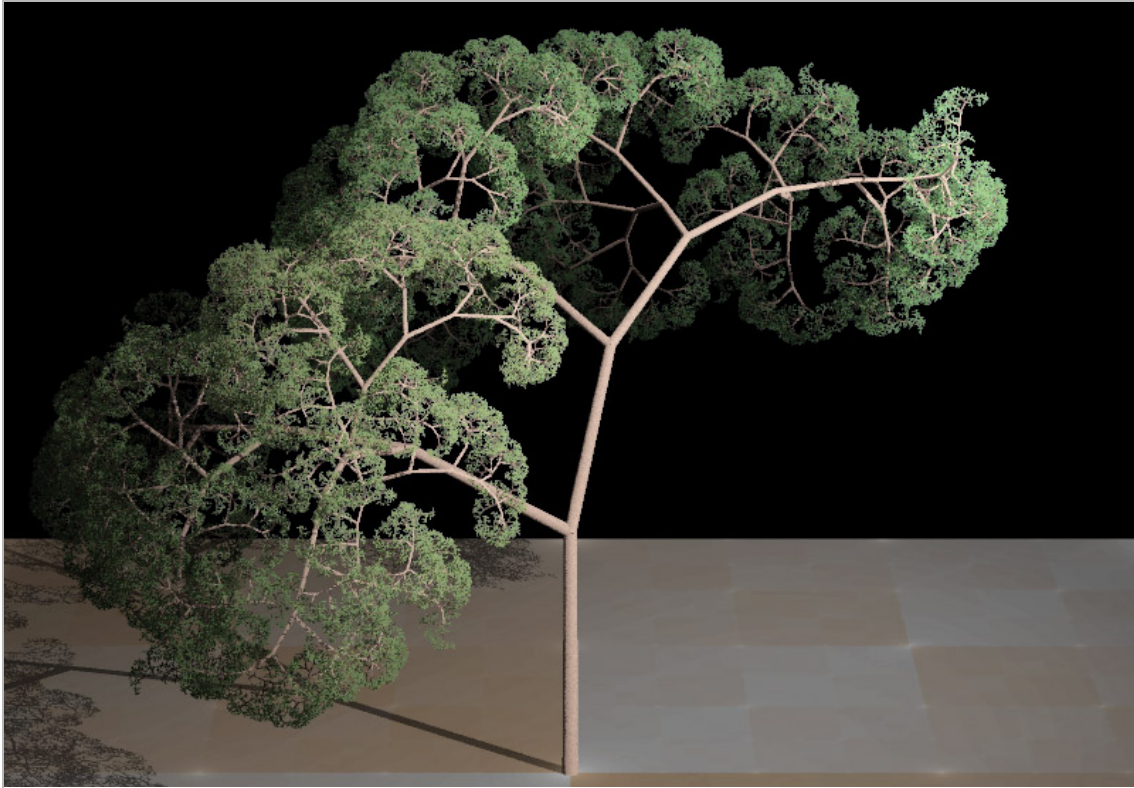


The Power of Exponents

Fast Track GRASP Math Packet

Part 1



Version 1.12

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<http://www.collectedny.org/ftgmp>

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Overview

Prerequisites	There are no prerequisites for this packet. As long as you are able to read this packet independently, you don't have to study any other math packets first.
Optional	You may find it helpful to complete the <i>Tools of Algebra: Expressions, Equations, & Inequalities</i> for an in-depth introduction to variables.

In this packet you will learn about exponents and roots as well as how to break numbers down and examine how they work.

In Part 1, you will study the following topics:

- Multiplication, including factors, multiples, and arrays
- Characteristics of numbers, including factors, prime factorization, and finding common factors between numbers
- An introduction to exponents, square roots and cube roots, with connections to geometry
- What it means when an exponent is 1 or less (fractional exponents, to the power of zero, and negative exponents)

In Part 2, you will build on what you learned in Part 1, and study the following topics:

- Place value, powers of ten, and scientific notation
- Powers of two and exponential growth
- Variables and exponents
- Operations with exponents (multiplication, division, and raising a power to a power)

In addition to the learning the topics above, you will find the following materials to help you:

- A review of the big ideas at the end of Part 2.
- High School Equivalency Test Practice Questions. You will practice all the concepts you have learned from this packet (parts 1 and 2) to work on these questions.
- A graphic organizer to study vocabulary is included, along with a vocabulary activity to review concepts. A glossary with important terms from this packet is also included for your study.
- Concept Circles can help you make connections between the concepts you have learned and help you remember those connections.

Assessment Questions

Calculator allowed

The following questions will help to see if this packet is right for you. Do your best to answer each question below. When you are finished with the questions, read our recommendations.

Question 1

Part I: What are all the factors of 36?

Part II: What is the prime factorization of 72? Use a factor tree or your own method to show how you know.

Question 2

Mark each of the following statements as True or False. Show your work.

A. $2^4 3^2 = (2 \times 4)(3 \times 2)$ _____

B. $\sqrt{144} = 2 \cdot 2 \cdot 3$ _____

C. $9 = (\sqrt[3]{27})^2$ _____

D. $(\sqrt{16})^3 = 48$ _____

The Power of Exponents (Part 1)

Question 3

Which equations below are true? Choose two and show how you know.

A. $(5^2)(5^3) = (5 \times 2)(5 \times 3)$

B. $2^3 5^0 = 0$

C. $2x^2 \cdot 3x^3 = 6x^5$

D. $4^2 = 4^5 \div 4^3$

Question 4

Which of the following is equal to $\frac{(x^5)(x^4)}{x^3}$?

A. $\frac{1}{3}$

B. x^3

C. $x^{20/3}$

D. x^6

Answer Key

Question 1

Part I: The factors of 36 are: 36, 18, 12, 9, 6, 4, 3, 2, 1

$$1 \times 36 = 36$$

$$2 \times 18 = 36$$

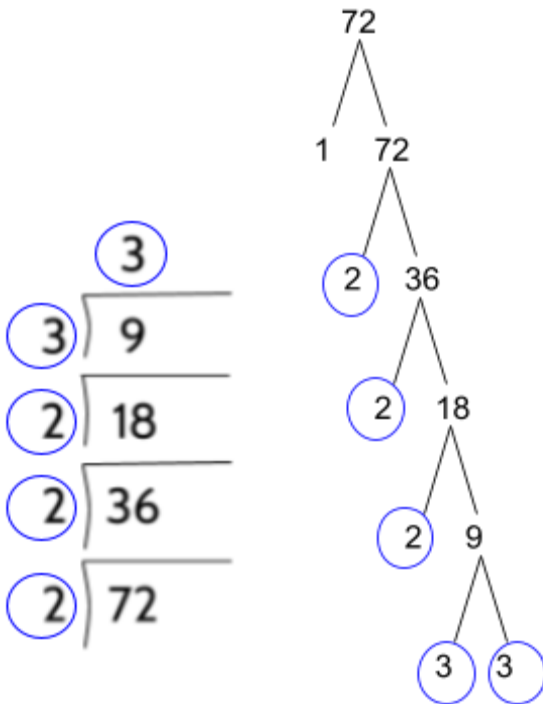
$$3 \times 12 = 36$$

$$4 \times 9 = 36$$

$$6 \times 6 = 36$$

Part II: The prime factorization of 72 = $2 \cdot 2 \cdot 2 \cdot 3 \cdot 3$

Students may show their work using a factor tree, the cake method, or their own method.



The Power of Exponents (Part 1)

Question 2

Choice B & C: B is true because both sides of the equal sign are equivalent to 12. The square root of 144 = 12 and $2 \cdot 2 \cdot 3 = 12$. C is true because the cube root of 27 is 3 and 3 squared is 9.

Question 3

Choices C & D.

C. $2x^2 \cdot 3x^3$ is the same as: $2 \cdot x \cdot x \cdot 3 \cdot x \cdot x \cdot x$. Simplified that would be $2 \cdot 3 \cdot x^6$ or $6x^6$

D. $4^5 \div 4^3$ is the same as $4 \cdot 4 \cdot 4 \cdot 4 \cdot 4$ divided by $4 \cdot 4 \cdot 4$. If we set up this division using a fraction bar we see that $4 \cdot 4 \cdot 4$ divided by $4 \cdot 4 \cdot 4$ equals 1. That leaves us with $4 \cdot 4$ or 4^2 .

$$\frac{4 \cdot 4 \cdot 4 \cdot 4 \cdot 4}{4 \cdot 4 \cdot 4}$$

Question 4

Choice D. x^6

Recommendations

Consider the following when making a decision about working through this packet:

- Student has some difficulty with Question 1 or 2: The student may choose to work through the whole packet, both Part 1 and Part 2.
- Student has some difficulty with Question 3 or 4: If a student comfortably answers Questions 1 & 2, but has some difficulty with Question 3 or 4, the student may feel confident enough to skip Part 1 of the packet and go directly to Part 2.
- Student comfortably answers all four questions: The student may choose to work on a different packet. However, it is recommended that students who skip this packet complete the Test Practice Questions in *The Power of Exponents, Part 2* for additional test practice before they take the GED exam.

This assessment asks students to demonstrate understanding of:

Question 1 (from *The Power of Exponents, Part 1*): Prime factorization and rewriting a number in exponential form (GED Algebraic Problem Solving Assessment Targets Content Indicators: Q.1.b)

Question 2 (from *The Power of Exponents, Part 1*): Square and cube roots, rules of exponents (GED Algebraic Problem Solving Assessment Targets Content Indicators: Q.2.b, Q.2.c)

Question 3 (from *The Power of Exponents, Part 2*): Order of operations, rules of exponents, multiplying and dividing exponents with the same base (GED Algebraic Problem Solving Assessment Targets Content Indicators: Q.2.a, Q.2.b, Q.2.c)

Question 4 (from *The Power of Exponents, Part 2*): Variable based rules of exponents (GED Algebraic Problem Solving Assessment Targets Content Indicators: A.1.h)

Welcome!

Congratulations on deciding to continue your learning! We are happy to share this study packet on geometry, focusing on two-dimensional shapes and the measurement of area. We hope that these materials are helpful in your efforts to earn your high school equivalency diploma. This group of math study packets will cover mathematics topics that we see on high school equivalency exams. If you study these topics carefully, while also practicing other math skills, you will increase your chances of passing the exam.

Please take your time as you go through the packet. You will find plenty of practice here, but it's useful to make extra notes for yourself to help you remember. You will probably want to have a separate notebook where you can recopy problems, write questions and include information that you want to remember. Writing is thinking and will help you learn.

After each section, you will find an answer key. Try to answer all the questions and then look at the answer key. It's not cheating to look at the answer key, but do your best on your own first. If you find that you got the right answer, congratulations! If you didn't, it's okay. This is how we learn. Look back and try to understand the reason for the answer. Please read the answer key even if you feel confident. We added some extra explanations and examples that may be helpful. If you see a word that you don't understand, try looking at the *Vocabulary Review* at the end of the packet. There are some strategies for learning new words described in the next few pages.

We hope you share what you learn with your friends and family. If you find something interesting here, tell someone about it! If you find a section challenging, look for support. If you are in a class, talk to your teacher and your classmates. If you are studying on your own, talk to people you know or try searching for a phrase online. Your local library should have information about adult education classes or other support. You can also find classes listed here: <http://www.acces.nysed.gov/hse/hse-prep-programs-maps>

You are doing a wonderful thing by investing in your own education right now. You have our utmost respect for continuing to learn as an adult.

Please feel free to contact us with questions or suggestions.

Best of luck!

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CUNY Adult Literacy and High School Equivalency Program

Vocabulary

It is important to understand mathematical words when you are learning new topics. The following vocabulary will be used a lot in this study packet:

base · evaluate · exponent · factor · multiple · power · square root · variable

In this first activity, you will think about each word and decide how familiar you are with it. For example, think about the word “cube.” Which of these statements is true for you?

- I know the word “cube” and use it in conversation or writing.
- I know the word “cube,” but I don’t use it.
- I have heard the word “cube,” but I’m not sure what it means.
- I have never heard the word “cube” at all.

In the chart on the next page, read each word and then choose one of the four categories and mark your answer with a ✓ (checkmark). Then write your best guess at the meaning of the word in the right column. If it’s easier, you can also just use the word in a sentence.

Here’s an example of how the row for “cube” might look when you’re done:

Word	I know the word and use the word	I know the word but don’t use it	I have heard the word, but I’m not sure what it means	I have never heard the word	My best guess at the meaning of the word (or use the word in a sentence)
cube	✓				like a box, all the sides are the same length

Complete the table on the next page.

The Power of Exponents (Part 1)

Word	I know the word and use the word	I know the word but don't use it	I have heard the word, but I'm not sure what it means	I have never heard the word	My best guess at the meaning of the word (or use the word in a sentence)
base					
evaluate					
exponent					
factor					
multiple					
power					
square root					
variable					

Why Exponents Matter

High school equivalency exams emphasize questions about exponents and roots. In this study packet, while learning about exponents and roots, you will break apart numbers and examine how they work. Then you will learn how to use exponents to solve problems. Finally, we will look at HSE practice questions involving exponents and roots.

But why should you care about exponents? The HSE test might be the main reason you are studying them now, but exponents can also be useful when thinking about numbers in the real world. Exponents are tools to help us recognize patterns, find solutions, calculate with large and small numbers, and analyze numbers to understand science, finance and technology. Understanding how to use exponents will give you the power to make sense of scientific and financial situations.

In the next few pages, you will be introduced to problems that exponents help us explore. We will come back to these problems later in the packet to understand them with exponents.

Counting Ancestors

We each have two parents.¹ And each of our parents have two parents, which means that we have four grandparents. They may not be alive, and it is possible we never met them, but we each have four grandparents who are our ancestors, biologically.

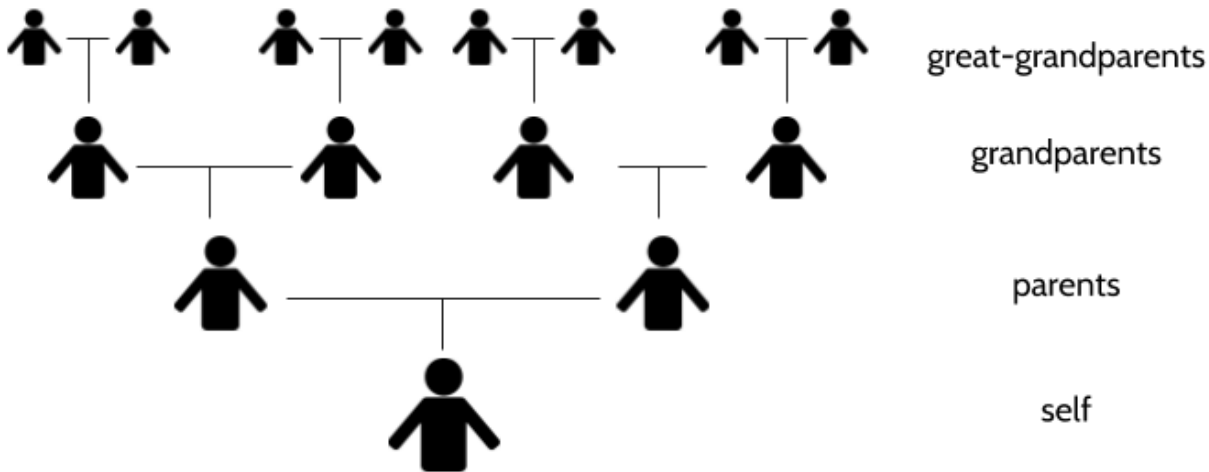
Your grandparents' parents are your great-grandparents. How many great-grandparents do we each have? How many great-great-grandparents? How would you figure it out?



¹ There are many kinds of families. Not all families have two parents. Some families have one parent. Some families have two fathers or two mothers. And there are families with people who take on parenting roles in different ways. There are many ways to make a family. For this math problem, we are talking about biological parents.

The Power of Exponents (Part 1)

Look at the following diagram and answer the questions below.



1) What do you notice?

2) Complete the following table.

generation	number of people
self	1
parents	2
grandparents	4
great-grandparents	
great-great-grandparents	
great-great-great-grandparents	

Really Large Numbers and Really Small Numbers

When studying science, we consider things that are really big, such as the distance between the planets, the weight of the sun, or the speed of light. We also study things that are really small, like the width of a blood cell, the size of a hydrogen atom or the speed that continents are moving across the surface of Earth. Here are some examples of those measurements in standard numbers:

Example	Measurement
Distance between Earth and the Sun	93,000,000 miles
Weight of the Sun	4,400,000,000,000,000,000,000,000,000 pounds
Speed of light	671,000,000 miles per hour
Width of a red blood cell	0.0003 inch
Diameter of an atom	0.000000004 inch
Speed of continental tectonic plates	0.000000006 miles per hour

What if you wanted to make some calculations with these measurements? For example, what is half the distance to the sun? How many miles would a tectonic plate move in 100 years? How far does light travel in a year?

These are the kinds of calculations scientists often make, but they have a hard time working with numbers like these. The numbers are so long. It would be nice to be able to write the numbers in a shorter way, so that they are easier to organize on paper. It is also really hard to keep track of all those zeros. How can I make sure that I have the right number of zeros?

Scientists use exponents to keep their calculations accurate. In this packet, you will learn a method called scientific notation which uses exponents to handle large and small numbers.

Examples of numbers in scientific notation:

The speed of light: 6.71×10^8 miles Width of a red blood cell: 3×10^{-4} miles per hour

Why Exponents Matter - Answer Key

1) There are different things you might notice. There is no wrong answer here.

2)

generation	number of people	
self	1	× 2
parents	2	× 2
grandparents	4	× 2
great-grandparents	8	× 2
great-great-grandparents	16	× 2
great-great-great-grandparents	32	× 2
great-great-great-great-grandparents	64	× 2
great-great-great-great-great-grandparents	128	

3) Amazingly, the answer is D) More than one million. Keep reading the packet to learn how this is possible.

Multiplication: Arrays, Factors and Multiples

Multiplication Practice

Understanding multiplication is essential to understanding exponents. Knowing your multiplication facts can also help you focus on other kinds of math while problem-solving. In the activities below, you will use multiplication facts and creative thinking to solve puzzles.

Look at the multiplication table below. You probably know many of the multiplication facts on this table. **Circle the ones you already know.**

×	1	2	3	4	5	6	7	8	9	10	11	12
1	1	2	3	4	5	6	7	8	9	10	11	12
2	2	4	6	8	10	12	14	16	18	20	22	24
3	3	6	9	12	15	18	21	24	27	30	33	36
4	4	8	12	16	20	24	28	32	36	40	44	48
5	5	10	15	20	25	30	35	40	45	50	55	60
6	6	12	18	24	30	36	42	48	54	60	66	72
7	7	14	21	28	35	42	49	56	63	70	77	84
8	8	16	24	32	40	48	56	64	72	80	88	96
9	9	18	27	36	45	54	63	72	81	90	99	108
10	10	20	30	40	50	60	70	80	90	100	110	120
11	11	22	33	44	55	66	77	88	99	110	121	132
12	12	24	36	48	60	72	84	96	108	120	132	144

The Power of Exponents (Part 1)

The numbers in the shaded boxes are called *factors*. You will learn more about factors later in the packet. The numbers you write in the white boxes are called *products* and are the results of multiplication.

$$\begin{array}{ccc}
 \text{factor} & & \text{factor} & & \text{product} \\
 \swarrow & & \downarrow & & \swarrow \\
 3 & \times & 4 & = & 12
 \end{array}$$

- 1) Complete this 1-5 multiplication table.
- 2) Look at these diagonal numbers (1, 4, 9, 16, 25). Do you notice anything special about these numbers?

×	1	2	3	4	5
1					
2					
3					
4					
5					

- 3) Complete the mixed-up 1-5 multiplication table below. A few have been done for you.

×	5	3	1	4	2
2	10				
4					8
1		3			
5					
3				12	

The Power of Exponents (Part 1)

The table below is called a Find the Factors³ 1-5 puzzle. The goal is to write the numbers 1 through 5 in the correct shaded boxes, then use those factors to fill in the missing products. To solve the puzzle, look at each given product and think about what two numbers can be multiplied to get that number.

For example, to get 16, you can multiply 1×16 or 4×4 . The number 16 isn't between 1 and 5, so it can't be one of the factors. The two numbers connected to 16 must both be 4.

4) Try it out. Use a pencil!

×	4				
					3
4	16		20		
		2			
			15		
				10	

Answer these questions after you have tried to solve the puzzle above.

5) What strategies did you use to figure out where to put the numbers 1 through 5 (the factors)?

If you're stuck: There are several ways to approach this puzzle. On the next page are the steps that I took to get started with this 1-5 puzzle.

³ The Find the Factors puzzles in this section are inspired by or are from findthefactors.wordpress.com, by Iva Sallay. Non-commercial use/copying permitted.

The Power of Exponents (Part 1)

×	4		5		
					3
4	16		20		
		2			
			15		
				10	

- With 4 on the left side, we now know that $4 \times ? = 20$. What can you multiply by 4 to get 20?
- Write the 5 in the factor row above.

×	4		5		
					3
4	16		20		
		2			
3	12		15		
				10	

- With the 5 on the factor row above, we now know that $5 \times ? = 15$. What can you multiply by 5 to get 15?
- Write the 3 on the left side.
- Now that we have 3 on the left and 4 above, we can multiply the two numbers to get 12.

×	4		5	2	
					3
4	16		20	8	
		2			
3	12		15	6	
5				10	

- Using the numbers 1 through 5, there is only one way to get a product of 10:

$$2 \times 5 = 10$$

- Do we put the 5 or the 2 on the line above? Since there is already a 5 on the factor row above, we can't put the 5 there. We can't repeat numbers on the shaded factor line. So the 2 must go above. That means the 5 will go on the left.
- Write the 2 above and the 5 on the left.
- With the 2 above, we can multiply by 4 to get 8 and by 3 to get 6.

Can you use the hints above to finish the rest of the puzzle now? The goal is fill every square with the right number.

The Power of Exponents (Part 1)

- 6) When you're finished, try the puzzles below. This is a Find the Factors 1-10 puzzle. Like the 1-5 puzzle, the goal is to write the correct number in each of the squares below. Use only one of each factor 1 through 10 in each shaded area.

Example: The two numbers that multiply to make 36 must be 6 and 6, since there is no other way to get 36 by multiplying numbers between 1 and 10.

×	6									
						1				
							25			
									100	
6	36									
		49								
			4							
										81
								16		
					64					

- 7) What strategies helped you solve this puzzle? What was challenging?

The Power of Exponents (Part 1)

8) Try this level ONE Find the Factors 1-12 puzzle. Write in the numbers 1 through 12 in the correct boxes vertically and horizontally.

×												
											1	
										144		
									4			
			121									
		81										
							9					
						100						
	64											
								25				
					36							
				16								

9) What strategies helped you solve this puzzle? What was challenging?

The Power of Exponents (Part 1)

10) This is a level TWO Find the Factors 1-10 puzzle.

×										
						14				
						4				
	3	9	27		18		15	21	24	12
						12				
						2				
						18				
						16				
						10				
						20				

11) What strategies helped you solve this puzzle? What was challenging?

The Power of Exponents (Part 1)

12) For a real challenge, try this level THREE 1-10 puzzle.

×										
	30	36								
									45	
					27					
			6							
										14
								28		
						32				
				8						
		60								

For many more Find the Factors puzzles, go to <http://findthefactors.wordpress.com>.

Working on these puzzles is a good way to practice the multiplication times tables, your problem-solving skills, and your understanding of factors.

Arrays

An *array* is an arrangement of objects in columns and rows. We often see arrays in the world, such as this pan of muffins.



13) How many muffins are there? How do you know?

This tray of eggs is arranged in an array as well.

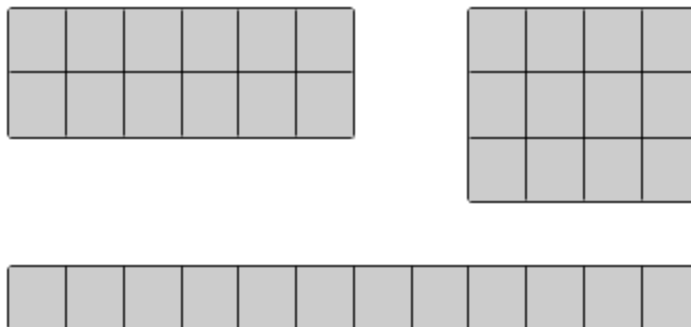


14) How many eggs are there? How do you know?

15) Look around you. What arrays do you see?

The Power of Exponents (Part 1)

These shaded squares are arranged in three different arrays. Each represents the number 12.



You might have noticed that each of the arrays above is in the shape of a rectangle. For that reason, they are sometimes called *rectangular arrays*.

If the rows and columns don't have an equal number of objects, it is not a rectangular array.

rectangular arrays



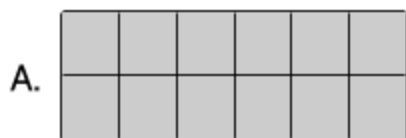
not rectangular arrays



The Power of Exponents (Part 1)

We can use arrays to think about multiplication. Arrays can also help us figure out the area of a shape. When we talk about the area of something we mean how many squares it would take to cover its surface. The length of a rectangle (or rectangular array) multiplied by its width gives the area (the number of squares).

Array A is 2 squares down and 6 squares across. 2×6 or 6×2 is 12, so the area is 12 squares. You can count the number of squares to make sure.



$$2 \times 6 = 12$$

$$6 \times 2 = 12$$

There are several different symbols for multiplication. An asterisk (*) or dot (·) is sometimes used to mean multiplication. Parentheses can also be used to indicate multiplication. Each of the following five equations mean the same thing: *2 multiplied by 6 is 12.*

$$2 \times 6 = 12 \quad 2 * 6 = 12 \quad 2 \cdot 6 = 12 \quad (2)(6) = 12 \quad 2(6) = 12$$

Array B could represent 1×12 or 12×1 .

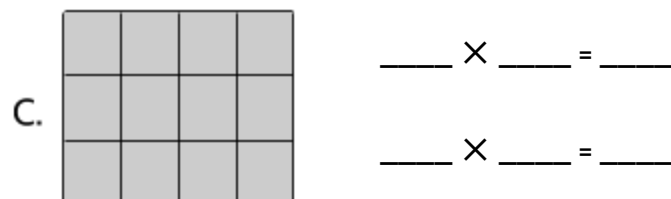


Each equation below gives the number of the squares in the area of the long rectangle.

$$1 \times 12 = 12$$

$$12 \times 1 = 12$$

16) Look at array C. How could you calculate the area of the rectangle?



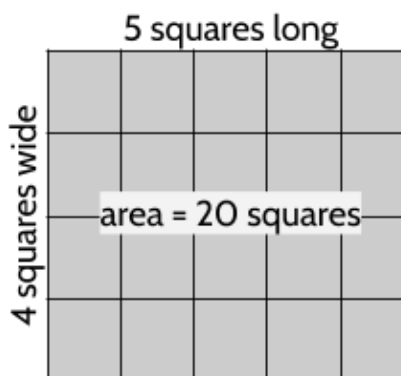
Factors

A factor is a number that can be multiplied to get another number. The numbers 1, 2, 3, 4, 6, and 12 are *factors* of 12. For example, 3 is a factor of 12 since $3 \times 4 = 12$.

Factors are numbers that are multiplied to make a *product*. 4 and 5 are both factors of 20.

$$\begin{array}{ccc} \text{factor} & & \text{product} \\ & \searrow & \swarrow \\ & 4 \cdot 5 = 20 & \end{array}$$

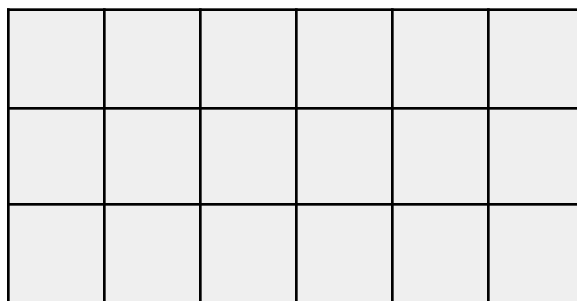
The length of the sides of a rectangle are factors of the rectangle's area.



You can also see factors in the multiplication table. The numbers in the shaded boxes are factors. The numbers in the white boxes are products.

×	1	2	3	4	5	6
1	1	2	3	4	5	6
2	2	4	6	8	10	12
3	3	6	9	12	15	18
4	4	8	12	16	20	24
5	5	10	15	20	25	30
6	6	12	18	24	30	36

The Power of Exponents (Part 1)



- 17) The area of a rectangle above is 18 squares. The length of one side is 3 squares long. What is the length of the other side?
- 18) If the area of a rectangle is 28 squares and the length of one side is 4 squares long, what is the length of the other side?

Use the multiplication table to answer the questions below.

19) $5 \times \underline{\quad} = 30$

20) $4 \times 3 = \underline{\quad}$

21) $24 = 6 \cdot \underline{\quad}$

22) $\underline{\quad} = 3 \times 6$

23) $16 = (4)(\underline{\quad})$

24) $\underline{\quad} \cdot 5 = 20$

\times	1	2	3	4	5	6
1	1	2	3	4	5	6
2	2	4	6	8	10	12
3	3	6	9	12	15	18
4	4	8	12	16	20	24
5	5	10	15	20	25	30
6	6	12	18	24	30	36

The Power of Exponents (Part 1)

Division is another way to think about factors. A factor can be divided into a whole number to get an answer with no *remainder* (a number left over after division).

Example	Conclusion
$12 \div 3 = 4$	3 is a factor of 12
$12 \div 6 = 2$	6 is a factor of 12
$20 \div 4 = 5$	4 is a factor of 20
$14 \div 4 = 3.5$	4 is not a factor of 14
$9 \div 6 = 1.5$	6 is not a factor of 9

Something to remember: Factors are whole numbers. A whole number is a number that can be written without using a fraction or a decimal. For example, 5 is a whole number. The numbers $\frac{2}{3}$ and 3.5 are not whole numbers. If you divide a number by one of its factors, you will get a whole number factor as an answer.

25) Is 7 a factor of 63? Please explain how you know.

26) Is 8 a factor of 20? Please explain how you know.

Multiples

Fill in the next three numbers in the following sequences.

	Sequence	What patterns do you see?
27)	2, 4, 6, _____, _____, _____, ...	
28)	3, 6, 9, _____, _____, _____, ...	
29)	5, 10, 15, _____, _____, _____, ...	
30)	10, 20, 30, _____, _____, _____, ...	

The Power of Exponents (Part 1)

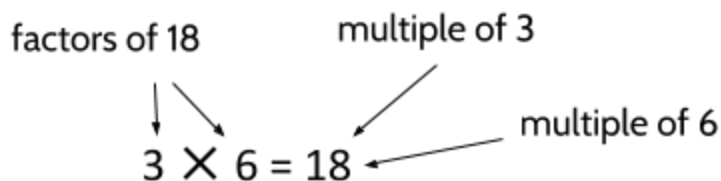
In the first series of numbers, you may have noticed that the numbers are going up by 2. Another way to look at this pattern is to see that the numbers are made by multiplying 2's.

$$2 \cdot 1 = 2 \quad 2 \cdot 2 = 4 \quad 2 \cdot 3 = 6 \quad 2 \cdot 4 = 8 \quad 2 \cdot 5 = 10 \quad 2 \cdot 6 = 12$$

The numbers 2, 4, 6, 8, 10 and 12 are *multiples* of 2. When you multiply 2 by another whole number, you will get a multiple of 2. Multiples of 2 are *even* numbers.

You can think of a multiple as the result of multiplication, similar to a product. The number 18 is a multiple of 3 because 3 six times is 18. This is because you can multiply 3 by a whole number to get 18. The number 18 is also a multiple of 6 because 6 three times is 18.

multiples of 3	multiples of 6
3, 6, 9, 12, 15, 18 , 21, 24, 27, 30, etc.	6, 12, 18 , 24, 30, 36, 42, 48, 54, 60, etc.



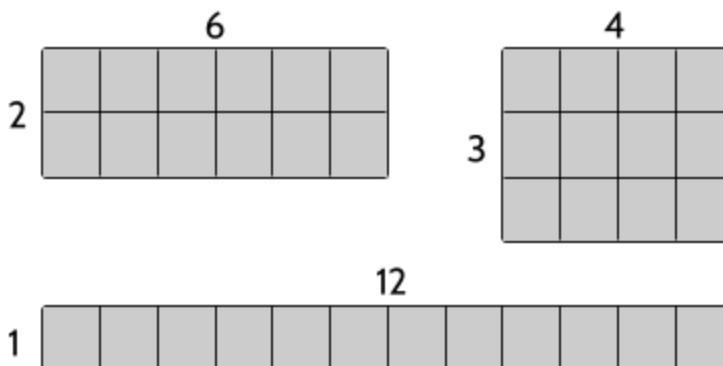
You might have heard multiples referred to as the “times table” for a particular number. For example, the multiples of 3 are sometimes called the “3 times table.” Calling these numbers the multiples of 3 is more precise.

Math language: You can say, “The product of 3 and 6 is 18.” Or you might say, “The product is 18.” When you use the word *multiple*, you have to say what number is being multiplied. For example, you could say, “18 is a multiple of 6,” or “All even numbers are multiples of 2.”

- 31) Is 45 a multiple of 5? Please explain your answer.
- 32) Is 62 a multiple of 12? Explain.
- 33) Is 5 a multiple of 25? Explain.
- 34) Is 12 a factor of 48? Explain.

Practice with Arrays, Factors and Multiples

The arrays below show all the factors of 12.



35) The complete list of factors for 12 is 1, 2, ____, ____, 6, & 12.

Two factors that multiply together to make a number are called a *factor pair*. 4 and 5 are a factor pair of 20, since $4 \cdot 5 = 20$.

36) How many factor pairs does 12 have?

37) Which of the following are not factor pairs of 12? Circle more than one answer.

A. 1 and 12

D. 3 and 6

B. 2 and 4

E. 4 and 3

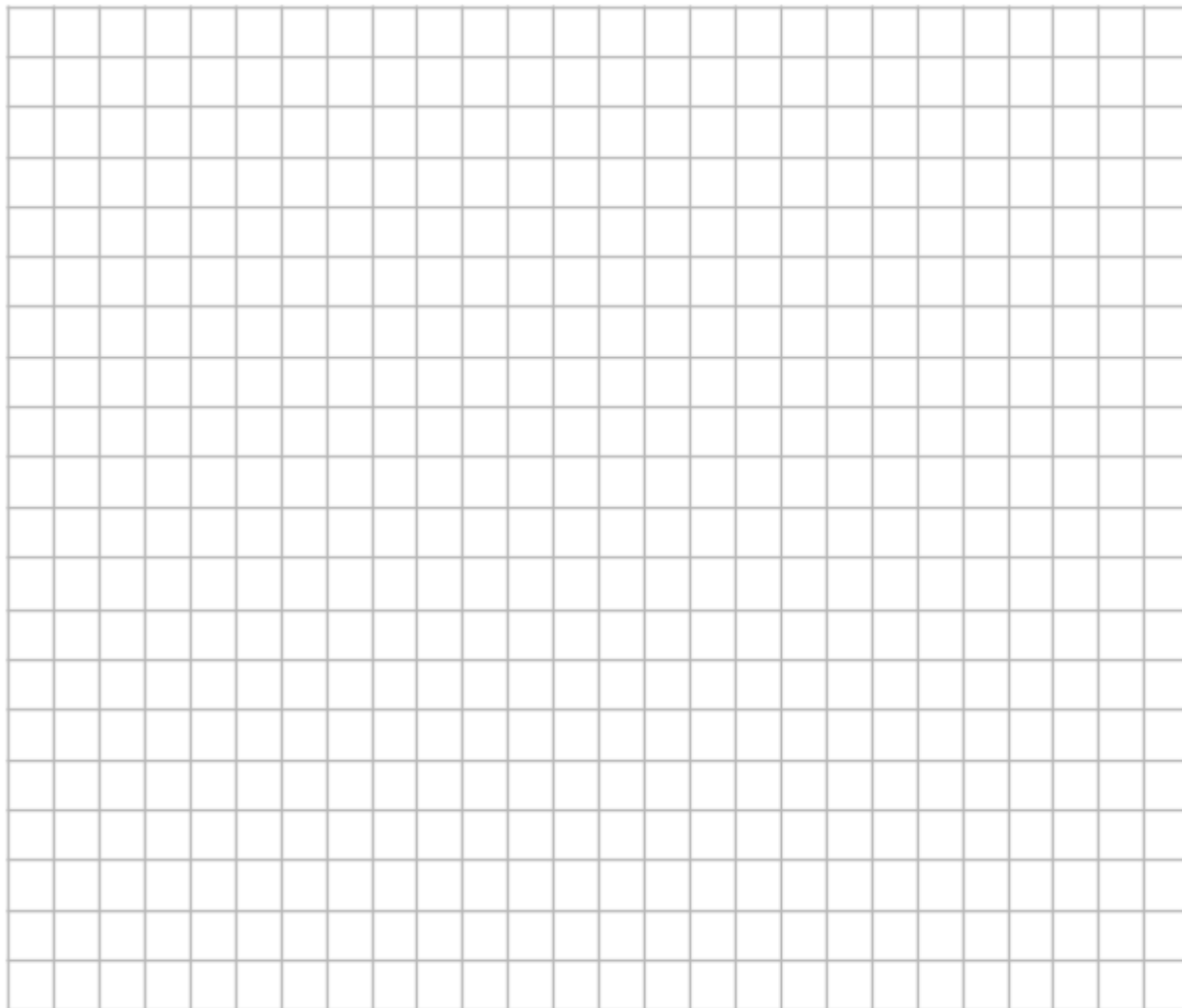
C. 3 and 4

F. 4 and 6

38) 12 is a multiple of what 6 numbers? _____

The Power of Exponents (Part 1)

- 39) Shade in squares to make as many different rectangular arrays as you can to represent the number 24.



- 40) Show all the ways that you can multiply two whole numbers to get 24. Use the arrays you drew on the grid above to find them all. The first factor pair is done.

$$\underline{1} \times \underline{24}$$

$$\underline{\quad} \times \underline{\quad}$$

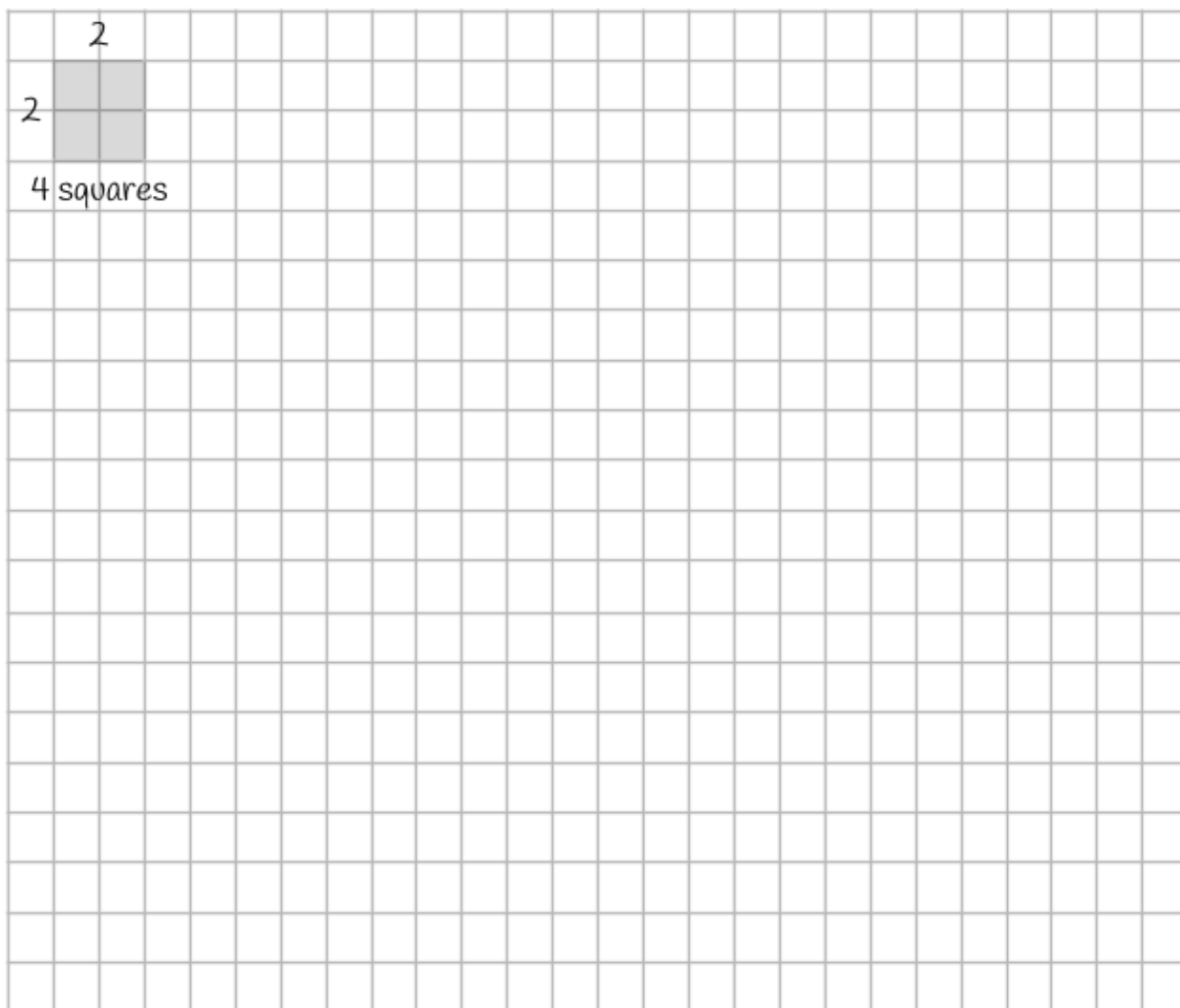
$$\underline{\quad} \times \underline{\quad}$$

$$\underline{\quad} \times \underline{\quad}$$

The Power of Exponents (Part 1)

- 41) The complete list of factors for 24 is 1, ____, ____, ____, ____, ____, ____, & 24.
- 42) How many factors does 24 have? _____
- 43) In the grid below, create as many arrays as you can to represent the numbers 4, 5, 10, 11, 13, 14 and 15. Label each array with the factors and the number. One array for 4 was done for you.

Make more than one array for each number if you can.



The Power of Exponents (Part 1)

44) Were you able to make more than one array for some of the numbers? Which ones?

The length of the sides of the rectangles are factors. The length and width of a rectangle make a factor pair.

45) Using the arrays you drew on the previous page, complete this table. The first row is done for you.

Number	Factor Pairs	Factors
4	$2 \cdot 2$ and $1 \cdot 4$	1, 2, 4
5		
10		
11		
13		
14		
15		

46) Choose the true statement below.

- A. All numbers have more than two factors.
- B. All numbers that have more than two factors are even.
- C. Some numbers have only two factors, 1 and the number itself.
- D. Some whole numbers can't be drawn as a rectangular array.
- E. Larger numbers always have more factors.

47) Which of the following is not a factor of 36?

- A. 2
- B. 6
- C. 9
- D. 12
- E. 15
- F. 36

Multiplication: Arrays, Factors and Multiples - Answer Key

- 1) You can check the multiplication if you are unsure of any answers.
- 2) They are made by multiplying a number by itself: 1×1 , 2×2 , 3×3 , etc.

3)

×	5	3	1	4	2
2	10	6	2	8	4
4	20	12	4	16	8
1	5	3	1	4	2
5	25	15	5	20	10
3	15	9	3	12	6

4)

×	4	1	5	2	3
1	4	1	5	2	3
4	16	4	20	8	12
2	8	2	10	4	6
3	12	3	15	6	9
5	20	5	25	10	15

- 5) Are your strategies similar to the ones on the next page?

6)

×	6	7	2	3	8	1	5	4	10	9
1	6	7	2	3	8	1	5	4	10	9
5	30	35	10	15	40	5	25	20	50	45
10	60	70	20	30	80	10	50	40	100	90
6	36	42	12	18	48	6	30	24	60	54
3	18	21	6	9	24	3	15	12	30	27
7	42	49	14	21	56	7	35	28	70	63
2	12	14	4	6	16	2	10	8	20	18
9	54	63	18	27	72	9	45	36	90	81
4	24	28	8	12	32	4	20	16	40	36
8	48	56	16	24	64	8	40	32	80	72

- 7) One strategy is to look at each product in the table and think about what two numbers can be multiplied to get that number. For example, to get 49, you can multiply 1×49 or 7×7 . The number 49 isn't between 1 and 10, so the numbers in the shaded rows connected to 49 must be 7.

8)

×	8	9	11	4	6	10	3	5	2	12	1	7
1	8	9	11	4	6	10	3	5	2	12	1	7
7	56	63	77	28	42	70	21	35	14	84	7	49
12	96	108	132	48	72	120	36	60	24	144	12	84
2	16	18	22	8	12	20	6	10	4	24	2	14
11	88	99	121	44	66	110	33	55	22	132	11	77
9	72	81	99	36	54	90	27	45	18	108	9	63
3	24	27	33	12	18	30	9	15	6	36	3	21
10	80	90	110	40	60	100	30	50	20	120	10	70
8	64	72	88	32	48	80	24	40	16	96	8	56
5	40	45	55	20	30	50	15	25	10	60	5	35
6	48	54	66	24	36	60	18	30	12	72	6	42
4	32	36	44	16	24	40	12	20	8	48	4	28

- 9) You might start with numbers that can be made with multiplication in just a few ways. For example, 25 is 5×5 . It is also 1×25 and 25×1 , but these require numbers bigger than 10.

The Power of Exponents (Part 1)

10)

×	1	3	9	10	6	2	5	7	8	4
7	7	21	63	70	42	14	35	49	56	28
2	2	6	18	20	12	4	10	14	16	8
3	3	9	27	30	18	6	15	21	24	12
6	6	18	54	60	36	12	30	42	48	24
1	1	3	9	10	6	2	5	7	8	4
9	9	27	81	90	54	18	45	63	72	36
8	8	24	72	80	48	16	40	56	64	32
4	4	12	36	40	24	8	20	28	32	16
5	5	15	45	50	30	10	25	35	40	20
10	10	30	90	100	60	20	50	70	80	40

- 11) One strategy is to look for numbers that have the same factor. For example, the numbers 3, 9, 27, 18, 15, 21, 24 and 12 are all the result of 3 multiplied by another number. So the shaded box on the left side must have a 3 for that row.

12)

×	5	6	2	1	3	8	10	4	9	7
6	30	36	12	6	18	48	60	24	54	42
5	25	30	10	5	15	40	50	20	45	35
9	45	54	18	9	27	72	90	36	81	63
3	15	18	6	3	9	24	30	12	27	21
2	10	12	4	2	6	16	20	8	18	14
7	35	42	14	7	21	56	70	28	63	49
4	20	24	8	4	12	32	40	16	36	28
8	40	48	16	8	24	64	80	32	72	56
1	5	6	2	1	3	8	10	4	9	7
10	50	60	20	10	30	80	100	40	90	70

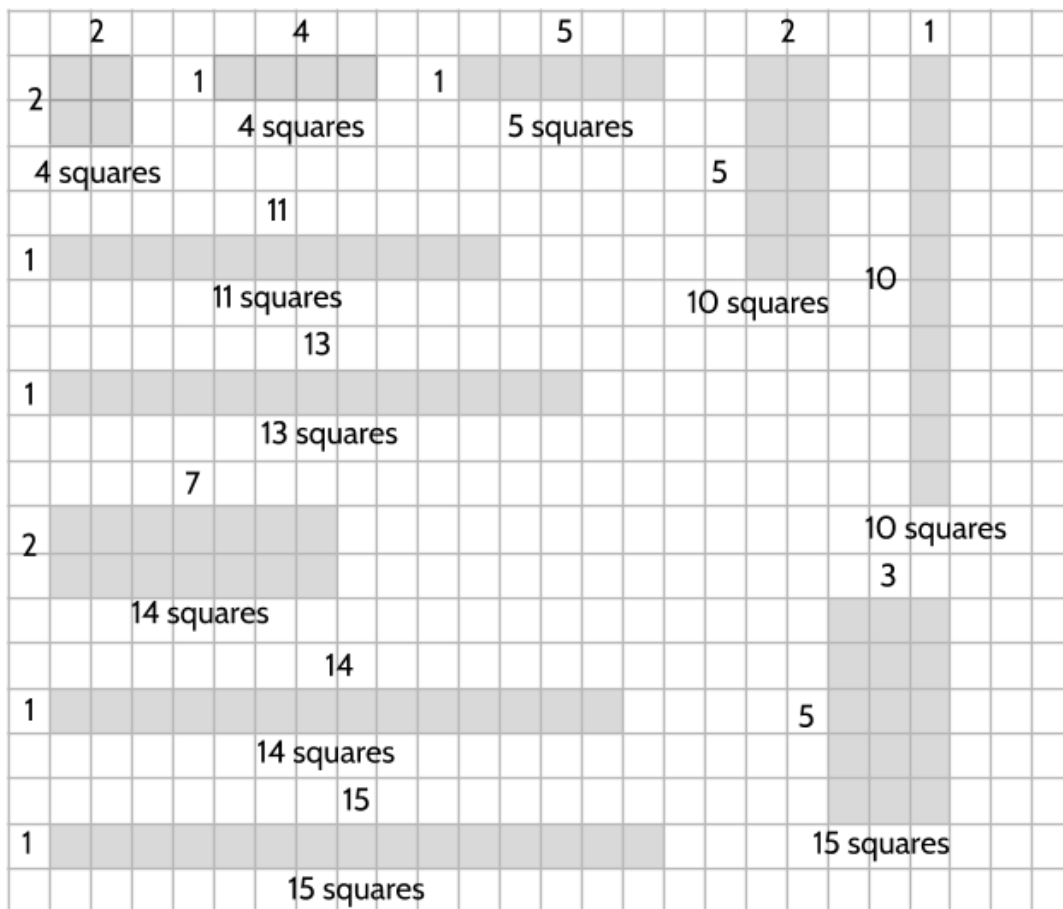
- 13) You could count or multiply 3 rows \times 4 columns to get 12 muffins.
- 14) You could count or multiply 5 rows \times 4 columns to get 20 eggs.
- 15) What do you see with rows and columns?
- 16) $3 \times 4 = 12$ and $4 \times 3 = 12$
- 17) 6
- 18) 7
- 19) 6
- 20) 12
- 21) 4
- 22) 18
- 23) 4

The Power of Exponents (Part 1)

- 24) 4
- 25) Yes. 7 is a factor of 63 because 7×9 equals 63. The number 9 is an whole number.
- 26) No. Even though $8 \times 2.5 = 20$, the number 8 is not a factor of 20 because 2.5 isn't a whole number.
- 27) 2, 4, 6, **8, 10, 12**, ... The numbers are going up by 2. They are all multiples of 2: 2×1 , 2×2 , 2×3 , etc.
- 28) 3, 6, 9, **12, 15, 18**, ... The numbers are going up by 3. They are all multiples of 3: 3×1 , 3×2 , 3×3 , etc.
- 29) 5, 10, 15, **20, 25, 30**, ... The numbers are going up by 5. They are all multiples of 5: 5×1 , 5×2 , 5×3 , etc.
- 30) 10, 20, 30, **40, 50, 60**, ... The numbers are going up by 10. They are all multiples of 10: 10×1 , 10×2 , 10×3 , etc.
- 31) Yes, because $5 \times 9 = 45$. Also, 45 divided by 5 equals 9, with no remainder.
- 32) No, because 62 divided by 12 equals 5.167. There is no whole number that can be multiplied by 12 to get 62.
- 33) No. 5 is a **factor** of 25. The number 25 is a multiple of 5.
- 34) Yes, because $12 \times 4 = 48$. The number 48 is a multiple of 12.
- 35) 1, 2, **3, 4**, 6, 12
- 36) Three: 1×12 , 2×6 , and 3×4
- 37) B, D, F
- 38) 12 is a multiple of 1, 2, 3, 4, 6, and 12.
- 39) You should be able to draw 4 different rectangles: 1 by 24, 2 by 12, 3 by 8, and 4 by 6
- 40) 1×24 , 2×12 , 3×8 , 4×6
- 41) 1, 2, 3, 4, 6, 8, 12, & 24
- 42) 8

The Power of Exponents (Part 1)

43)



44) It is possible to make more than one rectangular array for the numbers 4, 10, 14 and 15. There is only one array that you can make for each of the numbers 5, 11 and 13.

45)

Number	Factor Pairs	Factors
4	1 · 4 and 2 · 2	1, 2, 4
5	1 · 5	1, 5
10	1 · 10 and 2 · 5	1, 2, 5, 10
11	1 · 11	1, 11
13	1 · 13	1, 13
14	1 · 14 and 2 · 7	1, 2, 7, 14
15	1 · 15 and 3 · 5	1, 3, 5, 15

46) C

47) E

Breaking Down Numbers

We will start this section with a review of factors.

- 1) Find all the factors for each of the numbers below.

Ask yourself: What two numbers can I multiply to get _____? Are there any other ways?

If it is helpful, you can use the multiplication table on the next page.

Number	Factors
1	
2	
3	
4	1, 2, 4
5	1, 5
6	
7	
8	
9	
10	1, 2, 5, 10
11	1, 11
12	1, 2, 3, 4, 6, 12
13	1, 13
14	1, 2, 7, 14
15	1, 3, 5, 15
16	
17	
18	

Number	Factors
19	
20	
21	
22	
23	
24	1, 2, 3, 4, 6, 8, 12, 24
25	
26	
27	
28	
29	
30	
31	
32	
33	
34	
35	
36	

The Power of Exponents (Part 1)

You may want to use this 15 × 15 multiplication table while working on the previous page.

×	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
2	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30
3	3	6	9	12	15	18	21	24	27	30	33	36	39	42	45
4	4	8	12	16	20	24	28	32	36	40	44	48	52	56	60
5	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75
6	6	12	18	24	30	36	42	48	54	60	66	72	78	84	90
7	7	14	21	28	35	42	49	56	63	70	77	84	91	98	105
8	8	16	24	32	40	48	56	64	72	80	88	96	104	112	120
9	9	18	27	36	45	54	63	72	81	90	99	108	117	126	135
10	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150
11	11	22	33	44	55	66	77	88	99	110	121	132	143	154	165
12	12	24	36	48	60	72	84	96	108	120	132	144	156	168	180
13	13	26	39	52	65	78	91	104	117	130	143	156	169	182	195
14	14	28	42	56	70	84	98	112	126	140	154	168	182	196	210
15	15	30	45	60	75	90	105	120	135	150	165	180	195	210	225

Reminder:

The numbers on the sides are factors and the numbers in the unshaded boxes are products.

The Power of Exponents (Part 1)

2) Which numbers from 1 to 36 have the most factors?

3) Which number has exactly one factor?

4) Which numbers have exactly two factors?

5) Which numbers have an odd number of factors?

In the next section, we will look at numbers that have exactly two factors and numbers that have more than two factors.

Prime Numbers



The numbers 2, 3, 5, 7, 11, 13, 17, 19, 23, and 29 are the first ten *prime* numbers. A prime is a number with only two factors, 1 and itself. This means it cannot be divided into smaller whole numbers. For example, 7 is *divisible* only by 7 and 1. These are the only two whole numbers that divide into 7 with no remainder.

$$7 \div 1 = 7$$

$$7 \div 4 = 1.75$$

$$7 \div 7 = 1$$

$$7 \div 2 = 3.5$$

$$7 \div 5 = 1.4$$

$$7 \div 8 = 0.875$$

$$7 \div 3 = 2.33\dots$$

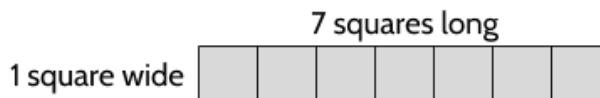
$$7 \div 6 = 1.166\dots$$

$$7 \div 9 = 0.77\dots$$

Other than 1 and 7, there are no other whole numbers that divide 7 to get a whole number answer.

You can use rectangles to think about prime numbers. Prime numbers can only be made into one kind of rectangle. Here are a few prime numbers as rectangles.

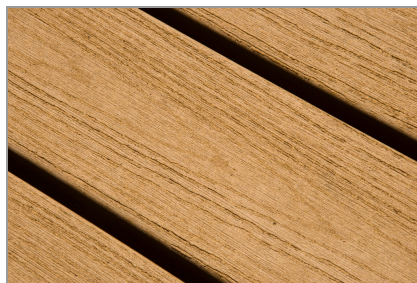
To make a rectangle with a prime number of squares, make the rectangle 1 square wide and the prime number of squares long. There is no other way to do it.



Check Your Understanding: What are the next three prime numbers after 29?

Composite Numbers

The numbers 4, 6, 8, 9, 10, 12, 14, 15, 16, and 18 are the first ten *composite* numbers. The word “composite” means something made from different parts. For example, composite wood is made in a factory from a combination of sawdust, natural fiber and plastic.



This looks like wood, but it's actually a *composite* of natural fibers and plastic.

A composite number is any number with more than two factors. For example, 14 is a composite number because it has four factors (1, 2, 7 and 14), which means that it can be divided by each of these numbers to get a whole number answer.

$$14 \div 1 = 14$$

$$14 \div 6 = 2.33\dots$$

$$14 \div 11 = 1.2727\dots$$

$$14 \div 2 = 7$$

$$14 \div 7 = 2$$

$$14 \div 12 = 1.66\dots$$

$$14 \div 3 = 4.66\dots$$

$$14 \div 8 = 1.75$$

$$14 \div 13 = 1.08$$

$$14 \div 4 = 3.5$$

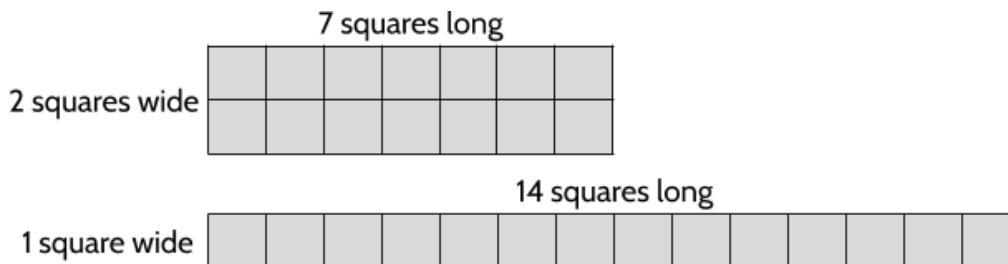
$$14 \div 9 = 1.55\dots$$

$$14 \div 14 = 1$$

$$14 \div 5 = 2.8$$

$$14 \div 10 = 1.4$$

You can use rectangles to think about composite numbers. Composite numbers can be made into at least two different rectangles. Two rectangles for 14 are below. The side lengths of the two rectangles represent the different factors of 14.



You can also see the factor pairs of 14 as the sides of these two rectangles. The two factor pairs are 2 & 7 and 1 & 14.

Composite numbers have three or more factors.

The Power of Exponents (Part 1)

6) Complete this table.

Number	Prime or Composite?	How do you know?
55	Composite	It has four factors: 1, 5, 11 and 55.
21		
43		
49		
37		

7) Which of these numbers are composite? Choose more than one.

- A. 2
- B. 3
- C. 6
- D. 9
- E. 17
- F. 21

The number 1 is unique because it only has one factor. All other whole numbers have at least two factors. The number 1 is sometimes called a *unit*. It is not prime or composite.

Answer to Check Your Understanding: The next three prime numbers after 29 are 31, 37, and 41. There are many, many prime numbers. In fact, there are an infinite number of prime numbers. Some mathematicians spend their careers searching for new prime numbers. All the small ones have been found. A recently discovered prime number has almost 25 million digits. It would take about 8,000 pages to type this prime number!

Prime Factorization

Prime numbers can be thought of as the building blocks of all other numbers. The word “prime” comes from the Latin word *prima*, which means “first.” All whole numbers can be written as the product of prime numbers.

For example, the number 6, which is a composite number, is made of the two prime numbers 2 and 3, since $2 \times 3 = 6$. The number 15 is made of the prime numbers 3 and 5, since they can be multiplied to get 15. All composite numbers can be made with prime numbers. It’s like the prime numbers are hiding inside the composite numbers!

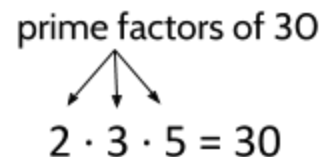
How can we find the prime numbers “hidden inside” composite numbers?

Let’s look at the number 30. You found out earlier that it has the factors 1, 2, 3, 5, 6, 10, 15, and 30. Some of these factors are prime and some are composite. The *prime factors* are 2, 3 and 5. The other numbers are composite.

The numbers 2, 3 and 5 are called the *prime factors* of 30 because:

- 2, 3, and 5 are each **factors** of 30: Each of these numbers can be divided into 30 with no remainder.
- 2, 3 and 5 are **prime** numbers: They each have only two factors and cannot be divided into smaller whole numbers.

2, 3 and 5 is also called the *prime factorization* of 30. It is like a secret code for the original number. If you multiply all the prime factors of a number together, you will get the number.



It doesn’t matter which order you multiply the prime factors. You should always get the original number in the end.

$$\begin{array}{l} (2 \times 3) \times 5 \\ 6 \times 5 \\ 30 \end{array}$$

$$\begin{array}{l} (2 \times 5) \times 3 \\ 10 \times 3 \\ 30 \end{array}$$

$$\begin{array}{l} (3 \times 5) \times 2 \\ 15 \times 2 \\ 30 \end{array}$$

Did you notice how the composite factors of 30 show up in the calculations above? Circle the 6, 10, 15, and 30.

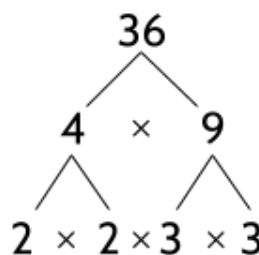
One way to find the prime factors of a number is to 1) find all the factors of the number and then 2) choose the factors that are prime numbers.

The Power of Exponents (Part 1)

Another method for finding prime factors is called a *factor tree*. In this method, you use factor pairs to break up a number until all the numbers are prime. When you are done, the diagram looks similar to a tree.

This example shows how the prime factorization of 36 is done with a factor tree.

1. Write the number you're factoring at the top.
2. Write one of the factor pairs of that number. It doesn't matter which.
3. If one of the factors in the pair is a composite number, write a factor pair for that number below.
4. Continue until all the numbers at the end of the "branches" are prime.
5. The numbers on the bottom of the tree are the prime factors. For example:

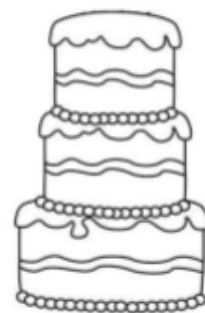
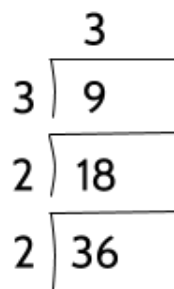


$$2 \times 2 \times 3 \times 3 = 36$$

Another method to find the prime factorization of a number is with the *cake method*. In this method, you keep dividing a number by its prime factors until all the answers are prime. When you are finished, it looks a little bit like a cake.

This example shows how the prime factorization of 36 is done with the cake method.

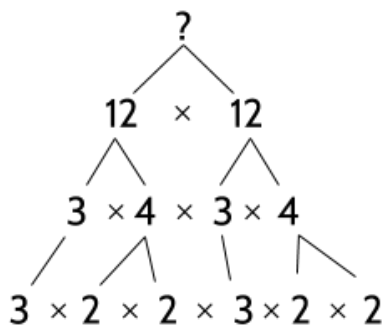
1. Write the number at the bottom under a division symbol.
2. Divide the number by one of its prime factors. Example: $36 \div 2 = 18$.
3. If the answer is not prime, divide it by one of its prime factors. Example: $18 \div 2 = 9$.
4. Repeat until your final answer is a prime number. Example: $9 \div 3 = 3$.
5. The numbers up the left side and on top are the prime factors. Example: $2 \cdot 2 \cdot 3 \cdot 3 = 36$



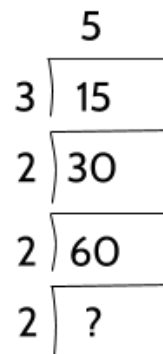
Either the factor tree method or the cake method will work for finding the prime factors of a number. You may also have your own method. Try them all and practice the one that works for you.

The Power of Exponents (Part 1)

- 8) What number is represented by the factor tree below?



- 9) What number is represented by the cake method below?



Using a factor tree, the cake method or a method of your own, complete the prime factorization for the numbers below. The prime factorization for prime numbers is just the number itself because the number 1 is not a prime number.

- 10) 60 12) 31 14) 64

- 11) 45 13) 56 15) 90

- 16) Which prime factorizations above include a prime number multiplied by itself many times?

Common Factors

Understanding factors can be helpful in different kinds of mathematics. For example, finding *common factors* of two or three numbers is useful when solving problems in fractions and algebra. We'll start by looking at a couple numbers and their factors. From our work above, we know that...

12 has the factors: 1, 2, 3, 4, 6, 12 and 18 has the factors: 1, 2, 3, 6, 9, 18

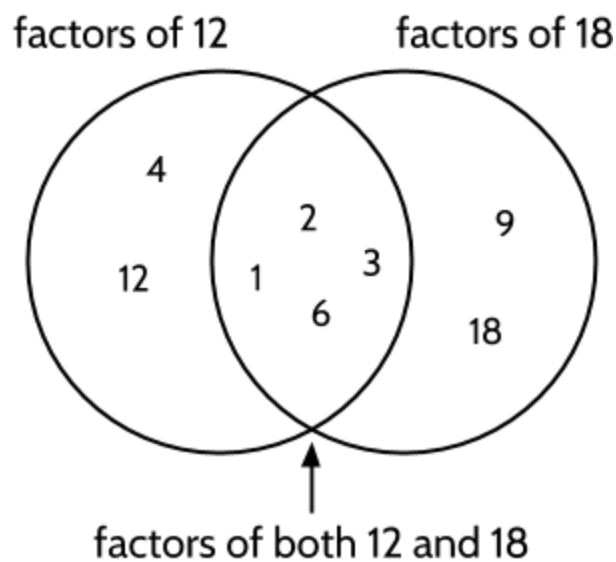
What are the *common factors* of these numbers? In this situation, *common* means something that both numbers have. If two apartments share a wall *in common*, it means that the wall is connected to both apartments (and you might be able to hear your neighbors). If two countries have a border *in common*, it means that the two countries are connected at that border (like between the United States and Mexico). If two numbers have factors *in common*, it means they both have those numbers in their list of factors.

17) Which factors do 12 and 18 have in common?

The diagram with overlapping circles on the right is called a Venn diagram. It shows how two groups of information are connected. We are using a Venn diagram here to show how the numbers 12 and 18 are related. The circle on the left shows the factors of 12 and the circle on the right shows the factors of 18. In the overlapping area in the center are factors of both numbers (1, 2, 3 and 6).

Once we know which factors are shared by two numbers, we can find the *greatest common factor*. In this situation, *greatest* means "largest." This is similar to how the word *great* is used when we say that 15 is *greater* than 7. We mean that 15 is a larger number than 7.

12 and 18 have the shared factors 1, 2, 3, and 6. The largest number in that list is 6, which means that 6 is the *greatest common factor* of 12 and 18.

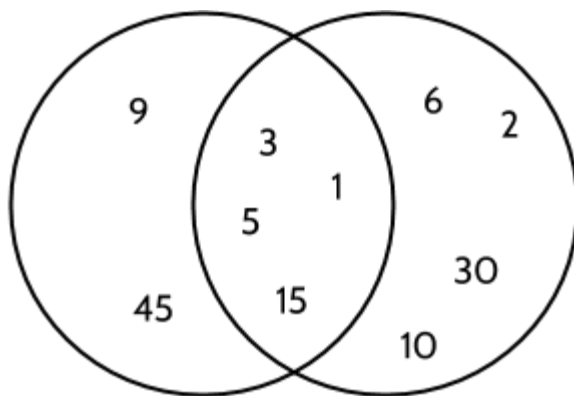


The Power of Exponents (Part 1)

Answer the following questions. You can use the chart on page 38 if it is helpful.

- 18) What are the common factors of 8 and 20?
- 19) What is the greatest common factor of 9 and 27?
- 20) What is the largest number that divides evenly into both 12 and 21? How do you know?

Two numbers and their greatest common factor are shown in this Venn diagram.



- 21) The factors in the left circle (9 and 45) belong to which number?
- 22) The factors in the right circle (2, 6, 10, 30) belong to which number?
- 23) What is the greatest common factor of the two numbers?

Breaking Down Numbers - Answer Key

1)

Number	Factors	Number	Factors
1	1	19	1, 19
2	1, 2	20	1, 2, 4, 5, 10, 20
3	1, 3	21	1, 3, 7, 21
4	1, 2, 4	22	1, 2, 11, 22
5	1, 5	23	1, 23
6	1, 2, 3, 6	24	1, 2, 3, 4, 6, 8, 12, 24
7	1, 7	25	1, 5, 25
8	1, 2, 4, 8	26	1, 2, 13, 26
9	1, 3, 9	27	1, 3, 9, 27
10	1, 2, 5, 10	28	1, 2, 4, 7, 14, 28
11	1, 11	29	1, 29
12	1, 2, 3, 4, 6, 12	30	1, 2, 3, 5, 6, 10, 15, 30
13	1, 13	31	1, 31
14	1, 2, 7, 14	32	1, 2, 4, 8, 16, 32
15	1, 3, 5, 15	33	1, 3, 11, 33
16	1, 2, 4, 8, 16	34	1, 2, 17, 34
17	1, 17	35	1, 5, 7, 35
18	1, 2, 3, 6, 9, 18	36	1, 2, 3, 4, 6, 9, 12, 18, 36

- 2) 36 has nine factors, which is the most. 24 and 30 are in second place, each with eight factors.
- 3) 1
- 4) The bold numbers: 2, 3, 5, 7, 11, 13, 17, 19, 23, 29, and 31 all have exactly two factors: 1 and the number itself. For example, the two factors for 13 are 1 and 13.
- 5) 1, 4, 9, 16, 25, and 36. Do you notice anything special about these

numbers? These are the only numbers on the list that can be represented by arrays that are perfect squares.

6)

Number	Prime or Composite?	How do you know?
55	Composite	It has four factors: 1, 5, 11 and 55.
21	Composite	It has four factors: 1, 3, 7 and 21.
43	Prime	It has only two factors: 1 and 43.
49	Composite	It has three factors: 1, 7 and 49.
37	Prime	It has only two factors: 1 and 37.

- 7) C, D, F
- 8) 144
- 9) 120
- 10) $2 \cdot 2 \cdot 3 \cdot 5$
- 11) $3 \cdot 3 \cdot 5$
- 12) 31 (The number 31 is prime so it can't be broken down any more.)
- 13) $2 \cdot 2 \cdot 2 \cdot 7$
- 14) $2 \cdot 2 \cdot 2 \cdot 2 \cdot 2 \cdot 2$
- 15) $2 \cdot 3 \cdot 3 \cdot 5$
- 16) 64, which is $2 \cdot 2 \cdot 2 \cdot 2 \cdot 2 \cdot 2$
- 17) 1, 2, 3 and 6

The Power of Exponents (Part 1)

18) 1, 2, and 4

21) 45

19) 9

22) 30

20) 3. The factors of 12 are 1, 2, 3, 4, 6 and 12. The factors of 21 are 1, 3, 7, and 21. These are the numbers that divide evenly into each number. 3 divides evenly into both numbers, with no remainder. There aren't any larger numbers that divide evenly into both numbers. (This question is another way of asking for the greatest common factor.)

23) 15

Using The Power of Exponents

Multiplication is Repeated Addition

Multiplication is a way to show addition that repeats over and over. Imagine there are seven kids and you want to give each one three pieces of candy. How many total pieces of candy will you give away?

You could use addition, adding $3 + 3 + 3 + 3 + 3 + 3 + 3$ to get 21. A shorter way would be to multiply 7×3 to get 21. Adding seven copies of 3 is the same as multiplying 7×3 .

$$\begin{array}{ccc}
 \text{number of kids} & & \text{number of candies} \\
 & \swarrow & \searrow \\
 & & \text{to each kid} \\
 3 + 3 + 3 + 3 + 3 + 3 + 3 & = & 7 \times 3
 \end{array}$$

Another example: If a school has five classrooms of students and each classroom has 20 students, how many students are there in the school?

$$\begin{array}{ccc}
 \text{number of classrooms} & & \text{number of students in} \\
 & \swarrow & \searrow \\
 & & \text{each classroom} \\
 20 + 20 + 20 + 20 + 20 & = & 5 \times 20
 \end{array}$$

1) Complete this table.

written as multiplication	written as repeated addition	written as a single number
3×2	$2 + 2 + 2$	6
4×7	$7 + 7 + 7 + 7$	
	$6 + 6 + 6 + 6 + 6$	
4×9		

What if you wanted a shorter way to write repeated *multiplication*? What is another way to write $2 \times 2 \times 2 \times 2 \times 2 \times 2$?

Exponents Show Repeated Multiplication

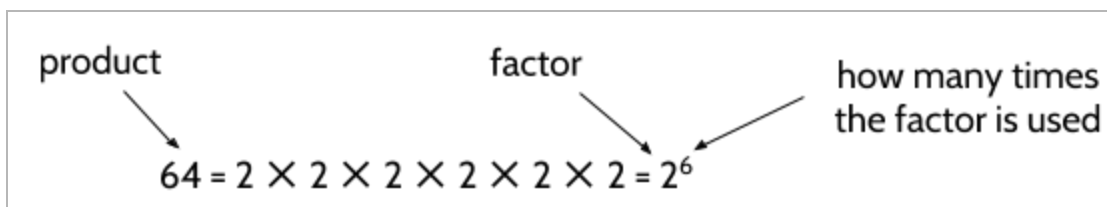
As we read in the last section, multiplication is a way to show addition that repeats. Instead of writing $5 + 5 + 5 + 5 + 5 + 5$, we can write 6×5 as a shorthand way of writing six copies of 5.

$$5 + 5 + 5 + 5 + 5 + 5 = 6 \times 5$$

Now, I want a fast way to write multiplication that repeats. For that, we can finally use exponents! First, let's remind ourselves of factors, which are used in multiplication.

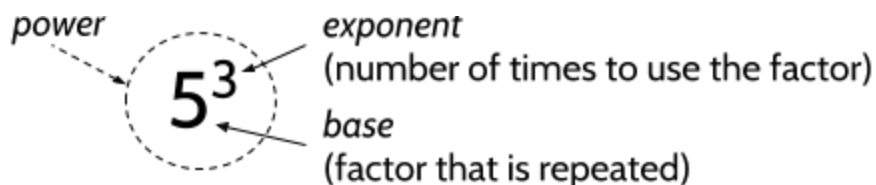
2) What is the prime factorization of 64? Show your method.

You should have found out that the prime factors of 64 are 2, 2, 2, 2, 2 and 2. This means that $2 \times 2 \times 2 \times 2 \times 2 \times 2$ is one way to write 64. (Check this with a calculator.) You can also write this repeated multiplication as 2^6 , which is read as "two raised to the sixth power." When you see 2^6 , it means 2 is used as a factor 6 times.



Writing 64 as a power

The number 5^3 is another example of a number written as a *power*. 5^3 means $5 \times 5 \times 5$ or 125. When a number is written as a power, it has a *base* and an *exponent*. The exponent (the smaller number above) tells us how many times the base (the number below) should be used as a factor in multiplication. This is also called *exponential form*.



In this number, the 5 should be used in multiplication 3 times: $5 \times 5 \times 5 = 125$.

The Power of Exponents (Part 1)

There are many ways to read 5^3 . The formal way to say it is:

five raised to the third power

You can also say “five to the third power,” “five to the third,” or “five cubed!” All of these phrases mean 5^3 .

3) Complete the following table.

Power	Repeated Multiplication	Number	Written in Words
2^3	$2 \times 2 \times 2$	8	<u>two</u> raised to the _____ power
	$3 \times 3 \times 3 \times 3$		_____ to the _____ power
5^2			_____ raised to the _____
	$2 \times 2 \times 2 \times 2$		_____ to the _____
			Four raised to the third power
1^3	$1 \times 1 \times 1$		

4) Paul says 5^2 is equal to 10. How would you help Paul understand his mistake?

5) True or False: $3^4 = 3 \times 3 \times 3 \times 3$

Explanation:

6) Which is greater, 4^3 or 3^4 ?

Explanation:

The Power of Exponents (Part 1)

7) True or False: $5^4 = 625$

Explanation:

8) Which exponential expression is equivalent to $8 \times 8 \times 8 \times 8$?

A. 4^4

B. 4^8

C. 8^4

D. 8^8

So far, we have only written numbers using one base and one exponent. For example, 81 is 3^4 ($3 \cdot 3 \cdot 3 \cdot 3$) and 32 is 2^5 ($2 \cdot 2 \cdot 2 \cdot 2 \cdot 2$).

Some numbers can be written as the product of different powers. For example, what if we wanted to write 72 with exponents? The prime factorization of 72 is $2 \cdot 2 \cdot 2 \cdot 3 \cdot 3$ (shown on the side). 72 has a mix of 2's and 3's as factors. Since 72 has three 2's and two 3's as factors, we can write it in exponential form like this:

$$2^3 \times 3^2$$

$$\begin{array}{r} 3 \\ 3 \overline{) 9} \\ 2 \overline{) 18} \\ 2 \overline{) 36} \\ 2 \overline{) 72} \end{array}$$

This is much shorter than $2 \cdot 2 \cdot 2 \cdot 3 \cdot 3$, but it means the same thing. We could even get rid of the multiplication symbol and write it like this:

$$2^3 3^2$$

When quantities like 2^3 and 3^2 are written next to each other, it means that the two quantities should be multiplied.

9) What number can be written as $2^3 5^2$?

The Power of Exponents (Part 1)

10) How would you write the number 100 in exponential form?

When numbers are written in their exponential form, we usually write the prime factors in order from smallest to largest. For example, 100 would be written 2^25^2 . If you wrote 5^22^2 , other people would know what you mean, but it might look strange to them.

11) Complete the table.

Number	Prime Factorization	Exponential Form
36	$2 \cdot 2 \cdot 3 \cdot 3$	
500		2^25^3
	$2 \cdot 2 \cdot 2 \cdot 3 \cdot 3$	
		3^15^2
90		

12) What is 1^5 ? Explain your answer.

13) Figure out the prime factorization of 144. Which of the following show 144 in exponential form?

A. 2^24^2

C. 2^33^2

B. 2^23^4

D. 2^43^2

14) The exponential form of a number is $3^25^17^1$. What is the number?

A. 19

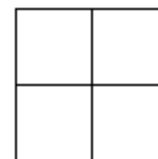
C. 315

B. 210

D. 945

Area and Exponents

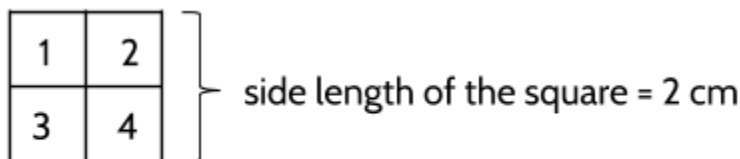
Area is a way to represent a number raised to the 2nd power. Measurements of area are written in square units. Look at the square on the right. Notice that the length of each side is the same.



15) What is the side length of the square? _____ centimeters

16) What is the area of the square? _____ square centimeters

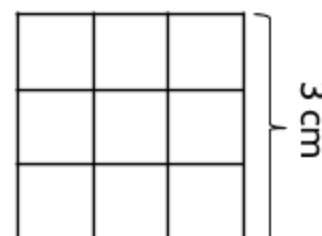
The side length of the square is 2 centimeters and there are a total of 4 square centimeters that make up the square. One way to find the area of the shape is to count the square centimeters that is made of.



area of the square = 4 square centimeters

17) What would be the area of a square with a side length of 3 centimeters?

_____ square centimeters



Another way to find the area of the square is to multiply the side length by the side length. For a square with a side length of 3 cm, the area is 3×3 or 9 square centimeters.



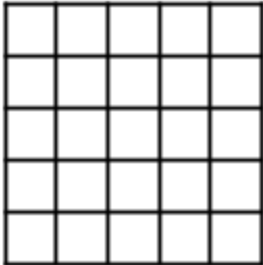
18) If the side length of a square is 10 centimeters, what would the area of the square be?

_____ square centimeters

The Power of Exponents (Part 1)

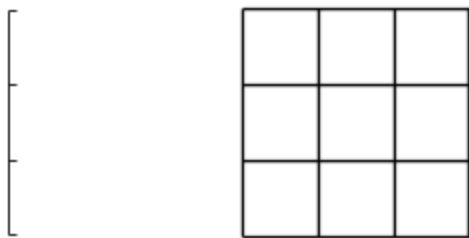
Look at a multiplication table. Here is the diagonal line of numbers that starts in the top left and goes towards the bottom right: 1, 4, 9, 16, 25, 36, 49, 64, 81, 100, 121, 144, etc. These are called *square numbers* because they can each be drawn as square arrays.

19) Complete the table below by drawing squares and filling in blanks.

Area (cm ²)	Drawing	Side length (cm)
1		1
4		
9		
16		
		

The Power of Exponents (Part 1)

To *square* a number means to start with a measurement of length and then draw a square where each side has that same length.




side length = 3 cm

side length *squared* = 9 square centimeters


If you have a side length of 3, then the square will have an area of 9. The number 3 *squared* equals 9.

For each of the given side lengths below, draw the rest of the square and calculate the area.

20) 

side length =

area =

21) 

side length =

area =

Note: You will find more practice with area in **Density: Area & Population Density, Part 1** and **Lines, Angles, and Shapes: Measuring Our World**.

The Power of Exponents (Part 1)

The area of a square can be calculated using the formula: $A = s^2$.

This formula can be read as “Area equals the side length squared” or “Area equals the side length to the second power.” To find the area, substitute the side length for s and then calculate the value of the exponent.

Here’s an example:

$$A = s^2$$

$$A = 5^2$$

$$A = 5 \times 5$$

$$A = 25$$

22) Complete the table below.

Side Length (s)	Area (A)	Calculation	Exponential Form
5 cm	25 cm ²	5 · 5	5 ²
2 cm			
3 cm			3 ²
4 cm			
8 cm			
10 cm			
1 cm			
	36 cm ²		
		7 · 7	
			9 ²
0.5 cm			

23) Complete this table for $A = s^2$.

Side length (s)	1	2	3	4	5	6
Area (A)						

Square Roots

When we hear the word “roots,” we usually think of the underground parts of plants. In mathematics, a *root* is the solution to an equation. Usually, the word *root* refers to the solution of an equation similar to this one:

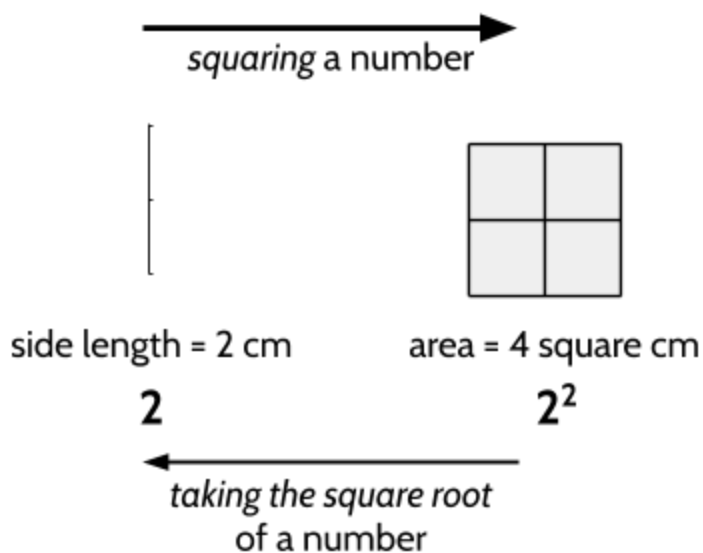
$$a^2 = 25$$

The root is a value of a that makes the expression $a^2 = 25$ true. To find the value of a in this equation, you can ask yourself, “What number times itself is equal to 25?” Since $5 \times 5 = 25$, a must be 5 or -5. Note: -5 is a possible solution since -5 multiplied by -5 also equals 25.)

24) If $b^2 = 36$, what is b ?

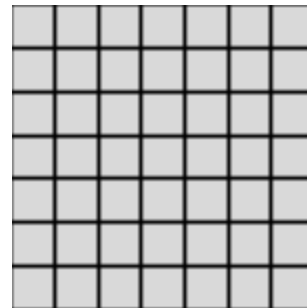
The values of a and b in the equations above are examples of *square roots*. As we saw above, you can think of *squaring* as starting with a number as the length of one side and then creating a square. The area is the square of the original length. The *square root* of a number is the opposite. It means starting with a number that is the area of a square and then finding the length of one side.

For example, if a square has an area of 4, the side length is 2. The square root of 4 is 2.



The Power of Exponents (Part 1)

25) What is the square root of the number represented by the grid to the right?



26) If the length of one side of a square is 11 (not pictured), what is the area of the square?

27) If the area of a square is 64, what is the length of one side?

The *radical* symbol ($\sqrt{\quad}$) is used to indicate a square root. For example:

$$\sqrt{25} = 5 \text{ (This equation can be read as "The square root of 25 is 5.")}$$

$$\sqrt{36} = 6 \text{ (The number 6 is the positive square root. -6 is also a square root of 25.)}$$

Another way to say square root is the *2nd root*. To find the square root or the 2nd root of a number, you can ask yourself, "What number can I multiply by itself to get the number I want?"

28) What is the square root of 81?

32) What is $\sqrt{3^2}$?

29) What is $\sqrt{49}$?

33) What is $\sqrt{x \cdot x}$?

30) What is $\sqrt{10 \cdot 10}$?

34) What is $\sqrt{3 \cdot 5 \cdot 3 \cdot 5}$?

31) What is the 2nd root of 9?

35) What is $(\sqrt{16})^3$?

Volume and Exponents

Volume can be used to represent a number raised to the 3rd power. Remember the different ways to say 2^3 .

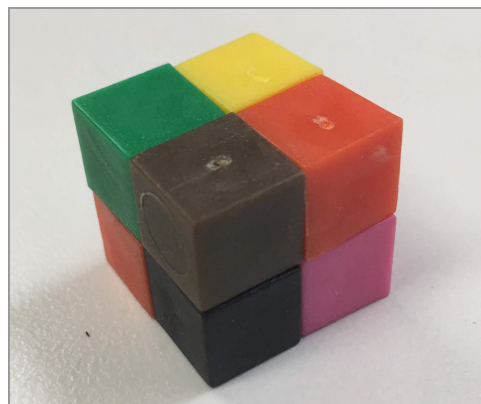
Two raised to the third power

Two to the third power

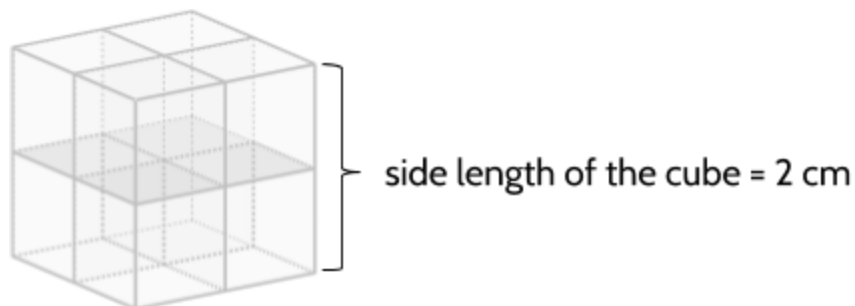
Two to the third

You can also say “two cubed.” Where does that come from? Similar to *squared*, this language can be understood by thinking about shapes.

In the multicolored cube on the right, the length of each side is 2 centimeters. This results in a total of 8 cubic centimeters that make up the cube. Each of the colored cubes is one cubic centimeter in volume. One way to find the volume of the multicolored cube is to count the cubic centimeters.



Do you see 8 different cubes inside the big cube?



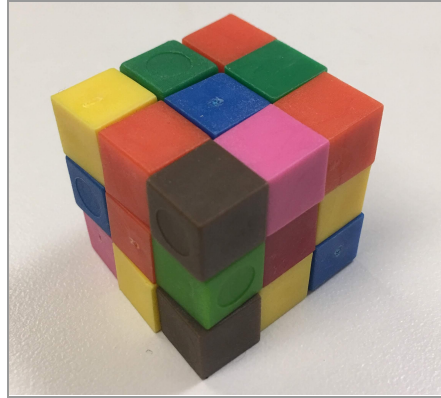
volume of the cube = 8 cubic centimeters

Note: You will find more practice with volume in **Density: Volume & Density of Matter, Part 2** and **Lines, Angles, and Shapes: Measuring Our World**.

The Power of Exponents (Part 1)

36) The cube below is 3 centimeters tall. What is the volume of the cube?

_____ cubic centimeters

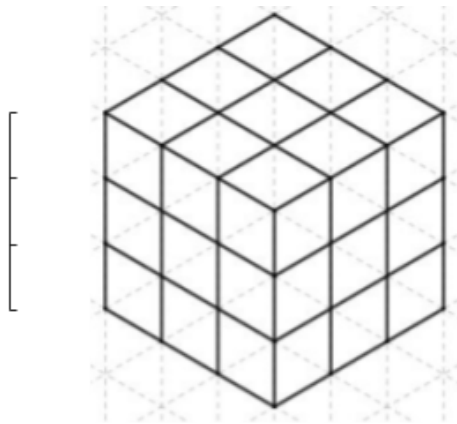


Another way to find the volume of a cube is to multiply the side length by the side length by the side length (in a cube, all three side lengths are the same). For a cube with a side length of 3 cm, the volume is $3 \times 3 \times 3$ or 27 cubic centimeters. We found the answer by *cubing* 3.

37) If the side length of a cube is 5 centimeters, what is the volume?

_____ cubic centimeters

When thinking about volume, to *cube* a number means to start with a measurement of side length and then make a cube where each side has that same length.

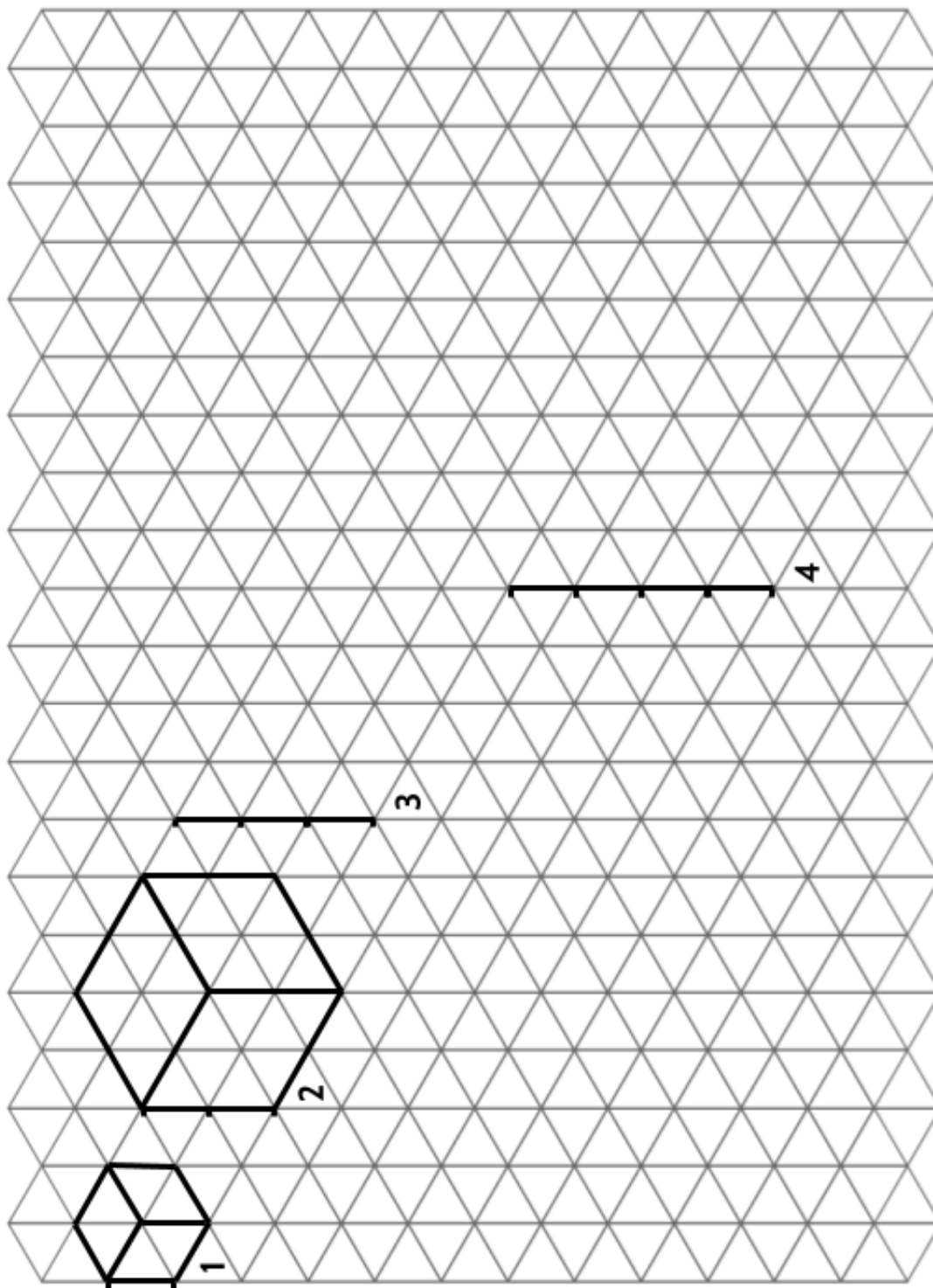


side length = 3 cm

side length *cubed* = 27 cubic centimeters

The Power of Exponents (Part 1)

- 38) The first two cubes are drawn for you. Use the side lengths to draw the next two cubes. How many cubic centimeters are there in each one? (Turn the paper sideways.)



The Power of Exponents (Part 1)

The volume of a cube can be calculated using this formula: $V = s^3$.

This formula can be read as “Volume equals the side length cubed” or “Volume equals the side length raised to the third power.” To find the volume, substitute the side length for s and then calculate the value of the exponent.

Here is an example:

$$V = s^3$$

$$V = 2^3$$

$$V = 2 \times 2 \times 2$$

$$V = 8$$

39) Complete the table below.

Side Length (s)	Volume (V)	Calculation	Exponential Form
2	8	$2 \cdot 2 \cdot 2$	2^3
3			3^3
4			
8			
10			
1			
		$6 \cdot 6 \cdot 6$	
	343		
			9^3
0.5			

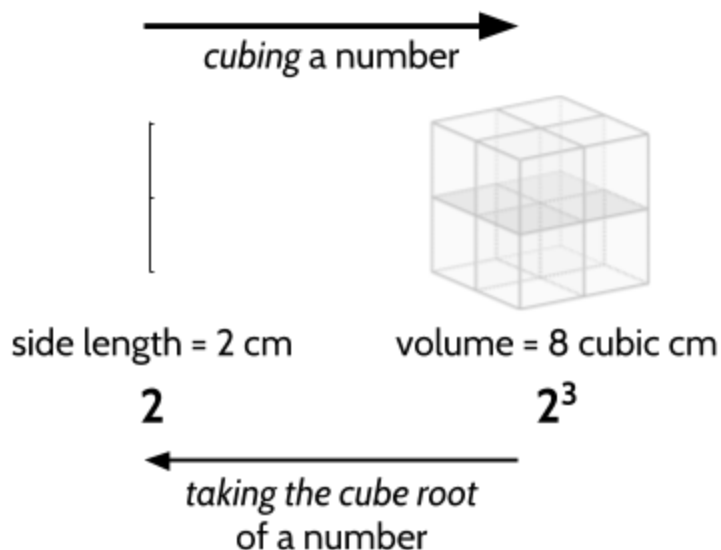
40) Complete this table for $V = s^3$.

Side length (s)	1	2	3	4	5	6
Volume (V)						

Cube Roots

Just as square roots are based on squares, *cube roots* are related to cubes. A number cubed is the volume of a cube with the number as a side length. The volume is the cube of the original length. The cube root of a number is the opposite. If the number is the volume of a cube, the cube root is the length of one side of that cube.

For example, if a cube has a volume of 8, the side length is 2. The cube root of 8 is 2.



A cube root is also a value of b that makes an equation like $b^3 = 8$ true. To find the value of b in this equation, you can ask yourself, "What number times itself and then times itself again is equal to 8?" Since $2 \times 2 \times 2 = 8$, in this equation b must be 2. This means that the cube root of 8 is 2.

- 41) If the length of one side of a cube is 4, what is the volume of the cube?
(In other words, what is the value of 4^3 ?)

- 42) If the volume of a cube is 125, what is the length of one side?
(In other words, what is the cube root of 125?)

The Power of Exponents (Part 1)

The *radical* symbol is also used to indicate a cube root. The only difference with the radical used for a square root symbol is that the cube root symbol has a small ³ in the radical:

$$\sqrt[3]{\quad}$$

For example:

$$\sqrt[3]{27} = 3 \text{ (This equation can be read as "The cube root of 27 is 3.")}$$

$$\sqrt[3]{64} = 4$$

Another way to say *cube root* is the *3rd root*. That's why the radical includes a 3. To find the cube root or the 3rd root of a number, you can ask yourself, "What number can I use as a factor in multiplication three times to get the number I want?"

43) What is the cube root of 216?

47) What is $\sqrt[3]{8^3}$?

44) What is $\sqrt[3]{343}$?

48) What is $\sqrt[3]{x \cdot x \cdot x}$?

45) What is $\sqrt[3]{10 \cdot 10 \cdot 10}$?

49) What is $\sqrt[3]{2 \cdot 3 \cdot 2 \cdot 3 \cdot 2 \cdot 3}$?

46) What is the 3rd root of 125?

50) What is $(\sqrt[3]{27})^2$?

51) If $\sqrt[3]{\quad}$ means the 3rd root, what do you think $\sqrt[4]{\quad}$ means?

What is $\sqrt[4]{16}$?

Finding Roots Using Factors

Finding Square Roots

There are a few ways to find the root of a number. One way is “guess and check.” For example, if you want to know the square root of 256, you can try multiplying numbers together until you find the number that multiplies with itself to equal 256. Take a few minutes to try that now. You might want to use a calculator.

We can also use factors to figure out the square root of any perfect square: 1, 4, 9, 16, 25, 36, and so on. Look back at the earlier section on prime factorization if you want a refresher.

Perfect Square	Prime Factors	Square Root
4	$2 \cdot 2$	2
9	$3 \cdot 3$	3
16	$2 \cdot 2 \cdot 2 \cdot 2$	4
25	$5 \cdot 5$	5
36	$2 \cdot 3 \cdot 2 \cdot 3$	6
49	$7 \cdot 7$	7
64	$2 \cdot 2 \cdot 2 \cdot 2 \cdot 2 \cdot 2$	8
81	$3 \cdot 3 \cdot 3 \cdot 3$	9
100	$2 \cdot 5 \cdot 2 \cdot 5$	10
256	$2 \cdot 2 \cdot 2 \cdot 2 \cdot 2 \cdot 2 \cdot 2 \cdot 2$	16

- 52) For each perfect square, compare the prime factors and the square root. What do you notice?

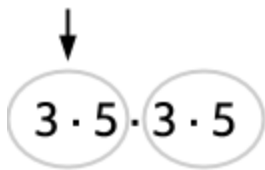
The Power of Exponents (Part 1)

The square root of a square number has half of the prime factors of the original number. For example, the prime factors of 100 are $2 \cdot 5 \cdot 2 \cdot 5$. The square root of 100 is 10, which is $2 \cdot 5$ (half of the factors of 100).

What is the square root of 225? Start by finding its prime factorization.

As shown on the right, the prime factors of 225 are 3, 3, 5, and 5.

To find the square root, split the prime factors into two equal groups of factors (see below). If the two groups on the left and the right are the same, the square root is one of the groups.



$$\begin{array}{r} 3 \\ 3 \overline{) 9} \\ \underline{9} \\ 0 \\ 5 \overline{) 45} \\ \underline{45} \\ 0 \\ 5 \overline{) 225} \\ \underline{225} \\ 0 \end{array}$$

You might notice that 3×5 is 15, so the square root is 15. Since you have the factors 3 and 5 twice in the group of factors for 225, the product is the same as 15×15 .

$$(3 \cdot 5) \cdot (3 \cdot 5) = 15 \cdot 15$$

$$\sqrt{3 \cdot 5 \cdot 3 \cdot 5} = 3 \cdot 5$$

$$\sqrt{225} = 15$$

- 53) The prime factorization of 324 is $2 \cdot 3 \cdot 3 \cdot 2 \cdot 3 \cdot 3$. What is the square root of 324?

Note: Make sure that you have two sets of the same factors. For example, the square root of $2 \cdot 2 \cdot 3 \cdot 3$ is not $2 \cdot 2$. It may be easier to write the factors as $2 \cdot 3 \cdot 2 \cdot 3$ so that you can see two groups of $2 \cdot 3$. (The square root of 36 is 6.)

You can only use the factor method of finding a square root with numbers that are perfect squares. It will not work for numbers that do not have two even sets of factors. For example, the prime factorization of 48 is $2 \cdot 2 \cdot 2 \cdot 2 \cdot 3$. There is no way to split these factors into two groups of the same factors. The square root of 48 is about 6.9 (not a whole number).

The Power of Exponents (Part 1)

You will see square roots represented in test questions in different ways.

with a radical	as the solution to an equation	$\frac{1}{2}$ as an exponent
$\sqrt{4}$	$c^2 = 4$	$4^{\frac{1}{2}}$
$\sqrt{100}$	$d^2 = 100$	$100^{\frac{1}{2}}$

Each of these ways of writing the square root mean the same thing. For example, each of the following means, “The square root of 4 is 2.”

$$\sqrt{4} = 2$$

$$\text{If } c^2 = 4, \text{ then } c = 2$$

$$4^{\frac{1}{2}} = 2$$

The last example is read as “four to the one-half power,” which is the same as “the square root of four.” Seeing $\frac{1}{2}$ as an exponent probably looks pretty strange. What do square roots have to do with half of something? Half of what? To get the square root of a number, you can use half of its prime factors. This is what we did on the last page.

54) Complete the following table.

Number	Prime Factors	Square Root ($\frac{1}{2}$ of factors)	Square Root (numeral)	Square Root (as a power)
16	$2 \cdot 2 \cdot 2 \cdot 2$	$2 \cdot 2$	4	$16^{\frac{1}{2}}$
100	$2 \cdot 5 \cdot 2 \cdot 5$			
121		11	11	$121^{\frac{1}{2}}$
225			15	

Decide whether the following statements are True or False.

55) $\sqrt{900} = 900^{\frac{1}{2}}$

58) $(x \cdot x)^{\frac{1}{2}} = x$

56) The square root of $2 \cdot 2 \cdot 3 \cdot 3$ is $2 \cdot 2$.

59) $\sqrt{144} = 2 \cdot 3 \cdot 3$

57) $400^{\frac{1}{2}} = 20$

60) $\sqrt{3 \cdot 3 \cdot 5 \cdot 5 \cdot 7 \cdot 7} = 3 \cdot 5 \cdot 7$

Finding Cube Roots

You can use “guess and check” to find the cube root or 3rd root of a number. For example, if you want to know the cube root of 343, you can try multiplying numbers together until you find the number that multiplies three times to give 343. Try that now. You might want to use a calculator.

We can also use factors to figure out the cube roots of some numbers. This will only work with numbers that are equal to a whole number raised to the 3rd power. They are called *perfect cubes*. You can take the cube root of any number, but only perfect cubes will have cube roots that are whole numbers. Here are some examples:

A “cube” number	Prime Factors	Cube Root
8	$2 \cdot 2 \cdot 2$	2
27	$3 \cdot 3 \cdot 3$	3
64	$2 \cdot 2 \cdot 2 \cdot 2 \cdot 2 \cdot 2$	4
125	$5 \cdot 5 \cdot 5$	5

- 61) A square root has one half of the prime factors of the original perfect square. The cube root has _____ the “cube” number.
- A. one-half of the prime factors of
 - B. one-third of the prime factors of
 - C. twice as many factors as
 - D. three times as many factors as

Look at the prime factors of each cube and compare them to the cube roots. The cube root is equal to the one-third of the prime factors of the cube number.

- 62) Find the cube root of 216.

The Power of Exponents (Part 1)

The prime factors of 216 are $2 \cdot 2 \cdot 2 \cdot 3 \cdot 3 \cdot 3$. Separate the factors into three equal groups.

$$(2 \cdot 3)(2 \cdot 3)(2 \cdot 3)$$

The cube root of 216 is 6.

- 63) The prime factorization of 27,000 is $2 \cdot 2 \cdot 2 \cdot 3 \cdot 3 \cdot 3 \cdot 5 \cdot 5 \cdot 5$.
What is the cube root of 27,000?

When using factors to find the cube root of a number, make sure that you have three sets of the same factors. For example, the cube root of $5 \cdot 5 \cdot 5 \cdot 2 \cdot 2 \cdot 2$ is not $5 \cdot 5$. It may be easier to write the prime factors as $2 \cdot 5 \cdot 2 \cdot 5 \cdot 2 \cdot 5$ so that you can see three groups of $2 \cdot 5$.

$$(2 \cdot 5)(2 \cdot 5)(2 \cdot 5) = 10 \cdot 10 \cdot 10$$

You can only use the factor method of finding a cube root with cubed numbers (a whole number raised to the 3rd power). The factor method will not work for numbers that do not have three sets of the same factors. For example, the prime factorization of 48 is $2 \cdot 2 \cdot 2 \cdot 2 \cdot 3$. There is no way to split these factors into three groups of the same factors. This means the cube root of 48 is not a whole number.

You can write cube roots in different ways. Each of the following mean the same thing:
“The cube root of 216 is 6.”

$$\sqrt[3]{216} = 6 \qquad \text{If } c^3 = 216, \text{ then } c = 6 \qquad 216^{\frac{1}{3}}$$

Notice that $8^{\frac{1}{3}}$ means the same as $\sqrt[3]{8}$. Both of these notations mean “the cube root of 8” or “the 3rd root of 8.” You can also say this as “8 to the one-third power.”

Decide whether the following statements are True or False.

64) $\sqrt[3]{2197} = 2197^{\frac{1}{3}}$

67) $(x \cdot x \cdot x)^{\frac{1}{3}} = x$

65) The cube root of $2 \cdot 2 \cdot 2 \cdot 5 \cdot 5 \cdot 5$ is 10.

68) $\sqrt[3]{1728} = 2 \cdot 2 \cdot 3$

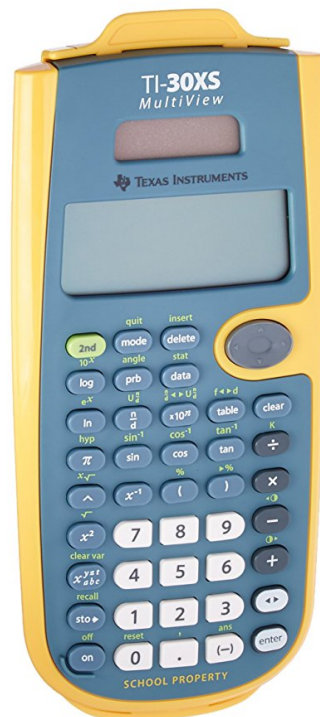
66) $216^{\frac{1}{3}} = 72$

69) $\sqrt[3]{3 \cdot 3 \cdot 3 \cdot 5 \cdot 5 \cdot 5 \cdot 7 \cdot 7 \cdot 7} = 3 \cdot 5 \cdot 7$

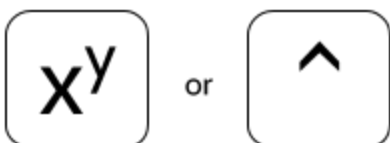
Calculator Practice

We recommend that you use a calculator as you work on the remainder of this packet. If you take the HSE exam, you will probably use the TI-30XS calculator. If you have access to this calculator, this is a good opportunity to start learning how to use it.

If you don't have the same calculator, it should still have functions for exponents and roots. You might notice that calculators have different buttons for exponents and roots.



Exponent keys:

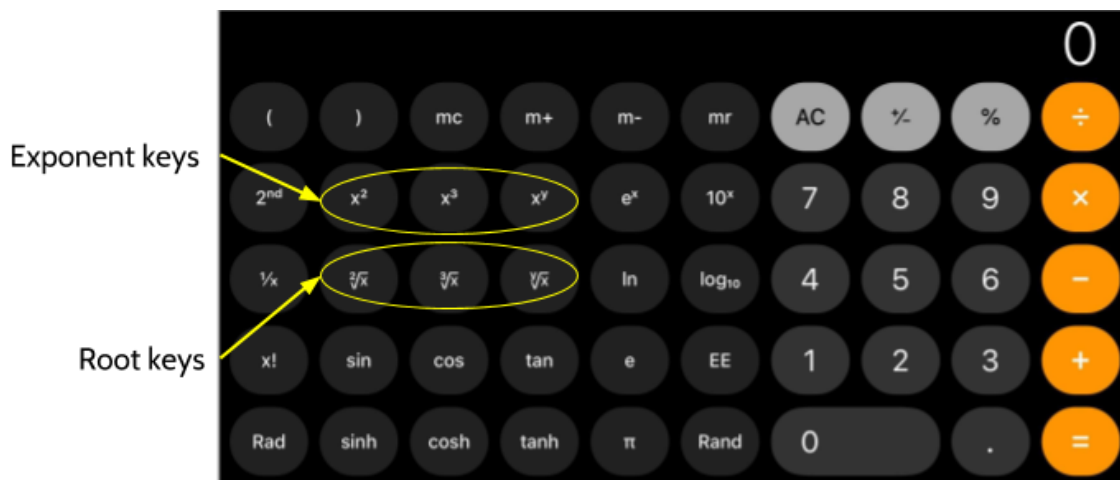


Root keys:



For practice on the TI30XS, go to <http://bit.ly/TI30XSHELP>.

If you have a smartphone, your calculator should have exponents and roots also. Open the calculator app and then turn your phone sideways. The scientific calculator should display.



Finding Squares and Cubes with a Calculator

In this exercise, you will practice finding square and cube numbers with a calculator.

The variable b stands for *base* and can represent any number we want to use for the base. On the TI-30XS calculator used on HSE exams, we use this symbol \wedge (called a *caret*) for entering exponents. The calculator uses this symbol because b^3 is another way to write b^3 .

square numbers
“to the second power”

$$b^2$$
$$b^2$$
$$b \times b$$

cube numbers
“to the third power”

$$b^3$$
$$b^3$$
$$b \times b \times b$$

You can remember to use \wedge by imagining it pushing the exponent up above the base. Other calculators may use a different button for roots. Here are some common calculator buttons for entering exponents.



calculator exponent buttons

All of these buttons mean “to the _____ power.” To use the exponent function, enter the number you are using for the base (b), then press the exponent button. Then, enter the exponent. Finally, press = or **enter**, depending on your calculator. Here is an example of 4^3 on two different calculators:

Press **4**, press \wedge , press **3**, press **enter**. Display should read **64**. (TI-30XS)

or

Turn phone, press **4**, press x^y , press **3**, press =. Display should read **64**. (smartphone)



Note: You can also use the  button to raise numbers to the 2nd power.

Calculate the following numbers with exponents.

70) What is 15^2 ? _____

72) What is 15^3 ? _____

71) What is 25^2 ? _____

73) What is 25^3 ? _____

74) You can use these buttons to calculate any power. What is 4^5 ?

Finding Square Roots and Cube Roots with a Calculator

In this exercise, you will use a calculator to quickly find square and cube roots. On the TI-30XS calculator, $\sqrt{\quad}$ is used for square roots and $\sqrt[3]{\quad}$ is used for cube roots (and other roots). You can actually use $\sqrt[x]{\quad}$ for all roots. Enter **2** for square roots, **3** for cube roots, **4** for 4th roots and so on.

square root
“the second root”

$$\sqrt{x}$$

$$x^{\frac{1}{2}}$$

cube root
“the third root”

$$\sqrt[3]{x}$$

$$x^{\frac{1}{3}}$$

Here is an example of $\sqrt[3]{64}$ (the cube root of 64) on two different calculators:

Press **3**, press  , press  , press **64**, press **enter**. (TI-30XS)

Display: 

or

Turn phone, press **64**, press $\sqrt[y]{x}$, press **3**, press =. Display should read **64**. (smartphone)

Calculate the following numbers with exponents.

75) What is $\sqrt{1024}$? _____

77) What is $\sqrt[3]{512}$? _____

76) What is $441^{\frac{1}{2}}$? _____

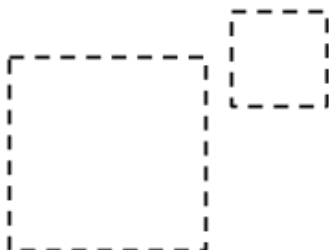
78) What is $729^{\frac{1}{3}}$? _____

79) You can use these buttons to calculate any root. What is the 5th root of 7776?

80) Sometimes the cube root of a number is not a whole number. What is $\sqrt[3]{48}$?

Practice with Powers

- 81) Directions: Use any two different numbers 1 through 10, using each number only once, to fill in the boxes below to make the largest value possible. Record your attempts below.



We tried 5 for the base and 4 for the exponent and got an answer of 625. Can you use different numbers between 1 and 10 to make a larger value?

Attempt	Base and Exponent	Value
1st try	5^4	625

Now use two different numbers from 1 to 10 to make the smallest value possible.

Attempt	Base and Exponent	Value

The Power of Exponents (Part 1)

82) Directions: Use the digits 1 to 9 to fill in the boxes to make this equation true. You can use a digit more than once. Record your attempts below. There is more than one way to make this equation true. How many solutions can you find?

$$\boxed{}^{\boxed{}} = 64$$

We tried 6 for the base and 3 for the exponent and got an answer of 216, which is not equal to 64. What digits will you try?

Attempt	Base and Exponent	Value	True or False?
1st try	6^3	216	False

Thanks to openmiddle.com for these activities.

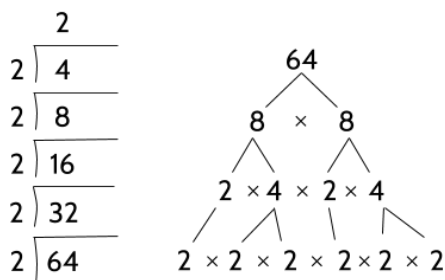
83) How many different ways are there to make this equation true with the numbers 1 through 9? How do you know?

Using The Power of Exponents - Answer Key

1)

written as multiplication	written as repeated addition	written as a single number
3×2	$2 + 2 + 2$	6
4×7	$7 + 7 + 7 + 7$	28
5×6	$6 + 6 + 6 + 6 + 6$	30
4×9	$9 + 9 + 9 + 9$	36

2) Your method may look like one of these:



3)

Power	Repeated Multiplication	Number	Written in Words
2^3	$2 \times 2 \times 2$	8	two raised to the third power
3^4	$3 \times 3 \times 3 \times 3$	81	three to the fourth power
5^2	5×5	25	five raised to the second
2^4	$2 \times 2 \times 2 \times 2$	16	two to the fourth
4^3	$4 \times 4 \times 4$	64	Four raised to the third power
1^3	$1 \times 1 \times 1$	1	one to the third power

4) Your explanation could use these facts:

$$5^2 = 5 \times 5 = 25$$

$$5 \times 2 = 10$$

5) True.

3^4 means 3 used as a factor 4 times: $3 \times 3 \times 3 \times 3$.

The Power of Exponents (Part 1)

6) $4^3 = 4 \times 4 \times 4 = 64$

$3^4 = 3 \times 3 \times 3 \times 3 = 81$

3^4 is greater than 4^3 .

7) True.

$5^4 = 5 \times 5 \times 5 \times 5 = 625$.

625 is also 25^2 , Do you know why?

8) 8^4

9) 200

10) 2^{25^2}

11)

Number	Prime Factorization	Exponential Form
36	$2 \cdot 2 \cdot 3 \cdot 3$	$2^2 3^2$
500	$2 \cdot 2 \cdot 5 \cdot 5 \cdot 5$	$2^2 5^3$
72	$2 \cdot 2 \cdot 2 \cdot 3 \cdot 3$	$2^3 3^2$
75	$3 \cdot 5 \cdot 5$	$3^1 5^2$
90	$2 \cdot 3 \cdot 3 \cdot 5$	$2^1 3^2 5^1$

12) $1 \times 1 = 1$, no matter how many times you multiply it. 1 to any power equals 1.

13) $2^4 3^2$

14) 315

15) 2 centimeters

16) 4 square centimeters

17) 9 square centimeters

18) 100 square centimeters

19)

Area (cm ²)	Side length (cm)
4	2
9	3
16	4
25	5

The Power of Exponents (Part 1)

20) 8 centimeters
64 square centimeters

21) 7 centimeters
49 square centimeters

22)

Side length (s)	Area (A)	Calculation	Exponential Form
5 cm	25 cm ²	5 × 5	5 ²
2 cm	4 cm ²	2 × 2	2 ²
3 cm	9 cm ²	3 × 3	3 ²
4 cm	16 cm ²	4 × 4	4 ²
8 cm	64 cm ²	8 × 8	8 ²
10 cm	100 cm ²	10 × 10	10 ²
1 cm	1 cm ²	1 × 1	1 ²
6 cm	36 cm ²	6 × 6	6 ²
7 cm	49 cm ²	7 × 7	7 ²
9 cm	81 cm ²	9 × 9	9 ²
0.5 cm	.25 cm ²	.5 × .5	.5 ²

23)

Side length (s)	1	2	3	4	5	6
Area (A)	1	4	9	16	25	36

24) 6 or -6

25) 7

26) 121

27) 8

28) 9 or -9

29) 7 or -7

30) 10

31) 3 or -3

32) 3

33) x

The Power of Exponents (Part 1)

- 34) $3 \cdot 5$ or 15
- 35) 64 or -64
- 36) 27 cubic centimeters
- 37) 125 cubic centimeters
- 38) Your drawings should look similar to the first two cubes. There should be 1, 8, 27, and 64 cubic centimeters shown in the drawings.
- 39)

Side length (s)	Volume (V)	Calculation	Exponential Form
2	8	$2 \times 2 \times 2$	2^3
3	27	$3 \times 3 \times 3$	3^3
4	64	$4 \times 4 \times 4$	4^3
8	512	$8 \times 8 \times 8$	8^3
10	1,000	$10 \times 10 \times 10$	10^3
1	1	$1 \times 1 \times 1$	1^3
6	216	$6 \times 6 \times 6$	6^3
7	343	$7 \times 7 \times 7$	7^3
9	729	$9 \times 9 \times 9$	9^3
0.5	.125	$.5 \times .5 \times .5$	$.5^3$

40)

Side length (s)	1	2	3	4	5	6
Volume (V)	1	8	27	64	125	216

- 41) 64
- 42) 5
- 43) 6
- 44) 7
- 45) 10
- 46) 5
- 47) 8
- 48) x

The Power of Exponents (Part 1)

49) $2 \cdot 3$ or 6

50) 9. The cube root of 27 is 3 and 3 squared is 9.

51) $\sqrt[4]{\quad}$ means the 4th root or “What number can be used as a factor 4 times to get 16?” For example, the 4th root of 16 is 2. This means that $2 \times 2 \times 2 \times 2 = 16$.

52) The square root of a number has half the factors of the square number. For example, the prime factors of 100 are $2 \cdot 5 \cdot 2 \cdot 5$. The square root of 100 is 10, which is $2 \cdot 5$ (half of the factors of 100). The square root is always equal to the product of half of the prime factors of a square number.

53) $2 \cdot 3 \cdot 3$ or 18

54)

Number	Prime Factors	Square Root (Factors)	Square Root (Numeral)	Square Root (as a Power)
16	$2 \cdot 2 \cdot 2 \cdot 2$	$2 \cdot 2$	4	$16^{\frac{1}{2}}$
100	$2 \cdot 5 \cdot 2 \cdot 5$	$2 \cdot 5$	10	$100^{\frac{1}{2}}$
121	$11 \cdot 11$	11	11	$121^{\frac{1}{2}}$
225	$3 \cdot 5 \cdot 3 \cdot 5$	$3 \cdot 5$	15	$15^{\frac{1}{2}}$

55) True.

56) False. The square root of $2 \cdot 2 \cdot 3 \cdot 3$ is $2 \cdot 3$. In other words, the square root of 36 is 6, not 4.

57) True. The square root of 400 is 20.

58) True.

59) False. The square root of 144 is $2 \cdot 2 \cdot 3$, which is 12.

60) True.

61) B

62) $2 \cdot 3$ or 6, because $6 \times 6 \times 6 = 216$

63) $2 \cdot 3 \cdot 5$ or 30

The Power of Exponents (Part 1)

- 64) True
- 65) True
- 66) False. $\frac{1}{3}$ of 216 is 72, but the cube root of 216 is 6.
- 67) True
- 68) True
- 69) True
- 70) 225
- 71) 625
- 72) 3375
- 73) 15,625
- 74) 1024
- 75) 32
- 76) 21
- 77) 8
- 78) 9
- 79) 6
- 80) Approximately 3.6
- 81) Try at least 4 different combinations of numbers. Remember that you can only use each number once. For example, 7^7 is not allowed.
- 82) See below.
- 83) There are three ways to make this equation true with the numbers 1 through 9:

$$8^2 = 64 \quad 4^3 = 64 \quad 2^6 = 64$$

For explanation of these three solutions, think about the prime factorization of 64:

$$2 \cdot 2 \cdot 2 \cdot 2 \cdot 2 \cdot 2$$

$2 \cdot 2 \cdot 2 \cdot 2 \cdot 2 \cdot 2$ is the same as 2^6 , which is one of the solutions. 2 and 6 are both numbers between 1 and 9.

You could also group the factors of 64 in a couple different ways:

$(2 \cdot 2) \cdot (2 \cdot 2) \cdot (2 \cdot 2)$ is the same as $4 \cdot 4 \cdot 4$ or 4^3 , which is another solution. 4 and 3 are both numbers between 1 and 9.

$(2 \cdot 2 \cdot 2) \cdot (2 \cdot 2 \cdot 2)$ is the same as $8 \cdot 8$ or 8^2 , which is another solution. 8 and 2 are both numbers between 1 and 9.

When the Exponent is 1 or Less

Using 1 as a Factor

By now, you have a lot of practice with powers like 2^2 . The exponent tells you how many times to use 2 as a factor in multiplication, so $2^2 = 2 \times 2$. But what do the powers below mean?

2^1

2^0

2^{-1}

What happens when you multiply a number by 1?

$5 \times 1 =$

$30 \times 1 =$

$1,000 \times 1 =$

$1.5 \times 1 =$

$.25 \times 1 =$

Any number multiplied by 1 is itself. Multiplying by 1 doesn't change the number.

To the Power of 1

- 1) Look for patterns in the table below. What do you notice?

Exponential Form	Factors and Divisors	Number
2^4	$1 \times 2 \times 2 \times 2 \times 2$	16
2^3	$1 \times 2 \times 2 \times 2$	8
2^2	$1 \times 2 \times 2$	4
2^1	1×2	2
2^0	1	1
2^{-1}	$1 \div 2$	$\frac{1}{2}$
2^{-2}	$1 \div 2 \div 2$	$\frac{1}{4}$
2^{-3}	$1 \div 2 \div 2 \div 2$	$\frac{1}{8}$

The Power of Exponents (Part 1)

The number 16 can be written as 2^4 because the number 2 is used as a factor four times ($2 \times 2 \times 2 \times 2$).

- 2) How many times is 2 used as a factor in 8?
- 3) How many times is 2 used as a factor in 4?
- 4) How many times is 2 used as a factor in 2?

Look back at the table on the previous page. If you follow the pattern in the factor column, 1×2 should be in the row for 2^1 . The number 2 has the number 2 as a factor once. It is just itself. This is why 2^1 is 2. A number raised to the 1st power equals the number. This is true of any number that is raised to the first power.

$$3^1 = 1 \cdot 3 = 3 \quad 15^1 = 1 \cdot 15 = 15 \quad x^1 = 1 \cdot x = x$$

To the Power of 0

You might want to say that a number raised to the zero power is 0.

Actually 2^0 doesn't equal 0 and 3^0 doesn't equal 0 either. So, what do 2^0 and 3^0 equal?

Look back at the table on the previous page.

- 5) Think about the number 1. How many times is 2 used as a factor in the number 1?

These may seem like a strange question. 1 doesn't have a 2 as a factor at all. That's what 2^0 means. It's a number with 0 factors of 2. This is one way to understand why 2^0 equals 1. The number 1 doesn't have any 2s as factors. Other than 1, which is always a factor, it doesn't have other numbers as factors. So, 2^0 is 1.

- 6) How many times is 3 used as a factor in the number 1?

The Power of Exponents (Part 1)

- 7) What is the value of x in this equation? $3^x = 1$
- A. 0
B. 1
C. 2
D. 3

If you chose $3^0 = 1$, you are correct. 3^0 means that the number has no factors of 3. The only factor it has left is 1, so the value of the number is 1. In fact, any base to the zero power is 1.

- 8) What is the value of 5^0 ?
- 9) What is the value of 35^0 ?
- 10) What is the value of x^0 ?

Negative Exponents

Let's look at the powers of 2 again for a way to understand 2^{-1} and numbers raised to negative exponents.

Exponential Form	2^{-3}	2^{-2}	2^{-1}	2^0	2^1	2^2	2^3
Number	$\frac{1}{8}$	$\frac{1}{4}$	$\frac{1}{2}$	1	2	4	8

As we move to the right, the numbers are doubling. As the exponent increases by 1, the numbers are multiplied by 2. For example, $2^2 \times 2$ is 2^3 and 4×2 is 8. The number for each power of 2 is doubling as the exponent increases by 1.

Now, look at what happens to the numbers as we move to the left in the table. The numbers are divided in half with each step to the left. We can see that $2^3 \div 2$ is 2^2 just as $8 \div 2$ is 4. As we move to the left in the table, we are dividing the number by 2. As the exponent goes down by 1, the number is divided by 2.

Can you see another reason why 2^0 equals 1? $2^2 \div 2$ is 2. And $2^1 \div 2$ is 1. So, 2^0 is 1.

The Power of Exponents (Part 1)

- 11) What other patterns do you notice when you look at this table of negative exponents?

Powers of 2		Powers of 3	
Positive Exponents	Negative Exponents	Positive Exponents	Negative Exponents
$2^1 = 2$	$2^{-1} = \frac{1}{2}$	$3^1 = 3$	$3^{-1} = \frac{1}{3}$
$2^2 = 4$	$2^{-2} = \frac{1}{4}$	$3^2 = 9$	$3^{-2} = \frac{1}{9}$
$2^3 = 8$	$2^{-3} = \frac{1}{8}$	$3^3 = 27$	$3^{-3} = \frac{1}{27}$
$2^4 = 16$	$2^{-4} = \frac{1}{16}$	$3^4 = 81$	$3^{-4} = \frac{1}{81}$

One thing you might notice is that these negative exponents don't result in negative numbers. The negative exponents make the numbers smaller, but $\frac{1}{2}$, $\frac{1}{4}$, and $\frac{1}{8}$ are positive numbers. So, the negative exponents aren't making the numbers negative. They are doing something else.

If you compare two powers, one with a positive exponent and one with the negative version of the same exponent, you can see that the two numbers are very similar. For example, 3^2 is 9 and 3^{-2} is $\frac{1}{9}$. In mathematics, this relationship is called a *reciprocal*. $\frac{1}{9}$ is the reciprocal of 9. $\frac{1}{16}$ is the reciprocal of 16. The number 27 is also considered the reciprocal of $\frac{1}{27}$. When you see 2^{-x} , ask yourself, "What is 1 divided by 2^x ?"

12) What is 4^{-3} ?

14) $\square^{-4} = \frac{1}{3 \cdot 3 \cdot 3 \cdot 3}$

13) If x^{-2} is $\frac{1}{25}$, what is x^2 ?

15) $6^{-2} = \frac{1}{\square}$

Using The Power of Exponents - Answer Key

- 1) There are different things you might notice. Here are a few:
 - All the factors and divisors start with 1. Some are multiplying by 2 and some are dividing by 2.
 - This chart includes negative exponents (2^{-1} , 2^{-2} , 2^{-3})
 - The negative exponents are equal to fractions ($\frac{1}{2}$, $\frac{1}{4}$, $\frac{1}{8}$)
 - 2^0 is 1, 2^{-1} is $\frac{1}{2}$, 2^{-2} is $\frac{1}{4}$
 - The numbers are being divided in half as we go down the chart
 - 2^{-2} is the same as 1 divided by 2 twice.
 - A negative exponent means division by the base number. A positive exponent means multiplication by the base number.
- 2) 3
- 3) 2
- 4) 1
- 5) 0. The number 1 doesn't have 2 as a factor.
- 6) 0. The number 1 doesn't have 3 as a factor.
- 7) A
- 8) 1
- 9) 1
- 10) 1
- 11) There are different things you might notice. Here are a few:
 - The chart shows positive exponents and negative exponents.
 - Negative exponents don't result in negative number values.
 - The negative sign in the exponent means you should put a 1 over the positive version of the exponent
- 12) $\frac{1}{64}$

The Power of Exponents (Part 1)

13) 25

14) 3

15) 36

Vocabulary Review

Glossary

You can use this section to look up words used in this math packet.

area (noun): The size of a flat surface, measured in square units

array (noun): An arrangement of objects in columns and rows

rectangular array: An *array* in the shape of a rectangle

base (noun): In a quantity represented as a power, the *base* is the factor being multiplied. For example, in the power 2^3 , the *base* is 2.

composite number: A number that has more than two factors

cube (noun): A box-shaped solid object that has six identical square faces

cube number (noun): A number which is the product of three numbers which are the same

perfect cube: Numbers like 1, 8, 27, 64, and 125 which can be formed into a *cube* of this number of blocks. All *perfect cubes* are a whole number to the third power. For example, $27 = 3^3$ and $125 = 5^3$.

digit (noun): The numbers 0-9 and the numerals that represent them: 0, 1, 2, 3, 4, 5, 6, 7, 8, 9. There are 5 digits in this number: 14,692. *Digit* can also mean “finger.”

divisible (adjective): A number is *divisible* by another number if it can be divided into the second number with no remainder. 21 is divisible by 3. 25 is not divisible by 3.

equation (noun): An expression that shows two mathematical expressions are equal (using = sign). $2^3 = 8$ is an *equation*. $5x + 3$ is an expression, not an *equation*.

equivalent (adjective): Having the same value. 4^3 and 64 are *equivalent*

estimate (verb): To make a rough guess at a number, usually without making written calculations

evaluate (verb): To calculate the value of something. If asked to *evaluate* 4^3 , your answer should be 64.

The Power of Exponents (Part 1)

even (adjective): Numbers that are divisible by 2.

expanded form (noun): A way of showing all the factors that are multiplied in a power. The *expanded form* of 3^4 is $3 \times 3 \times 3 \times 3$.

expression (noun): Numbers and symbols that show the value of something. 100, $5x + 3$, and 2^3 are all *expressions*. $5x + 3 = 23$ is an equation, not an *expression*. *Expressions* don't use equal signs.

exponent (noun): In a quantity represented as a power, the *exponent* shows how many times the base is multiplied. The exponent is shown as a smaller number up and to the right of the base. For example, in the power 2^3 , the *exponent* is 3.

exponential form: A way of writing values as a power using exponents. 3^4 is an *exponential form* of 81.

exponential growth: A growth pattern in which the unknown quantity or variable is an exponent and the base (factor) is larger than 1. The power 2^x produces *exponential growth* based on doubling or multiplying by 2. The power 3^x produces *exponential growth* based on tripling or multiplying by 3.

exponential decay: A change in numbers where the variable is an exponent and the base (factor) being multiplied is less than 1. As the exponent gets larger, the values get smaller. The power $(.5)^x$ represents *exponential decay*.

factor (noun): Whole numbers that are multiplied together to get another number. A number that can be divided into another number evenly, with no remainder.

prime factor: A factor of another number that itself has only 2 factors. 2, 3, and 5 are the prime factors of 30. The number 15 is a factor of 30, but it is not a *prime factor* of 30.

prime factorization: A way of representing numbers with all of their prime factors. $2 \times 3 \times 5$ is the *prime factorization* of 30. $2 \times 3 \times 3$ is the *prime factorization* of 18.

factor (verb): To split a number into its factors (see above definition of factors).

formula (noun): A rule or fact written with mathematical symbols. A formula usually has an equals sign = and two or more variables.

The Power of Exponents (Part 1)

multiple (noun): A number that can be divided by another number evenly, with no remainder. 25 is a *multiple* of 5.

numeral (noun): A symbol or name for a number. 12 and twelve are both *numerals*.

place value (noun): The value of each position in a number. In the number 4,967,285, the *place value* of the 7 is 1,000.

power (noun): A way of showing repeated multiplication. The base of a *power* shows what value is being multiplied. The exponent shows how many times it is multiplied.

powers of ten: 10^{-2} , 10^{-1} , 10^0 , 10^1 , 10^2 , etc.

powers of two: 2^{-2} , 2^{-1} , 2^0 , 2^1 , 2^2 , etc.

prime number (noun): A number that has exactly two factors (1 and itself)

product (noun): The result of multiplication. 4 times 5 gives a *product* of 20.

quotient (noun): The result of division. 20 divided by 5 gives a *quotient* of 4.

radical (noun): A symbol that means “root.” *Radicals* are used for square roots, cube roots, and other roots.

square root symbol: $\sqrt{\quad}$

cube root symbol: $\sqrt[3]{\quad}$

reciprocal (noun): Equal to 1 divided by a number or value. The *reciprocal* of 10 is $\frac{1}{10}$. The

reciprocal of x^3 is $\frac{1}{x^3}$.

remainder (noun): A number left over after division. 20 divided by 8 equals 2 with a *remainder* of 4.

root (noun): The solution to an equation, usually similar to $a^2 = 25$ or $a^3 = 8$

square root: A square root of a number is a value that, when multiplied by itself, gives the number. The *square root* of 25 is 5.

The Power of Exponents (Part 1)

cube root: A cube root of a number is a value that, when multiplied by itself and then multiplied by itself again, gives the number. The *cube root* of 8 is 2.

square (noun): a 4-sided, flat shape which has four straight and equal sides, and four right (90°) angles

square number (noun): A number which is the product of two numbers which are the same

perfect square: Numbers like 1, 4, 9, 16, 25, and 36, which can be formed into a square array of rows and columns. All *perfect squares* are a whole number to the second power. For example, $9 = 3^2$ and $25 = 5^2$.

variable (noun): A symbol that represents any number or a specific number. In the expression x^3 , x is a *variable* that could mean any number. In the equation $2v + 3 = 15$, the *variable* v must represent 6.

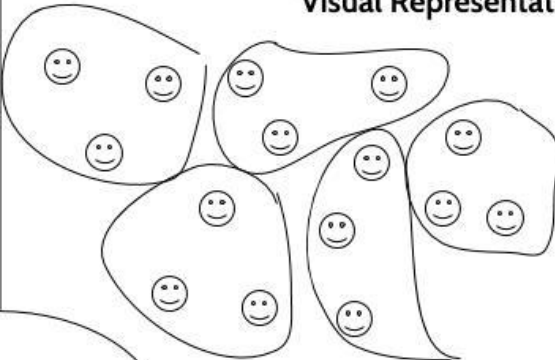
volume (noun): A measurement of the 3-dimensional space something takes up, measured in cubes

Using Graphic Organizers to Learn Vocabulary

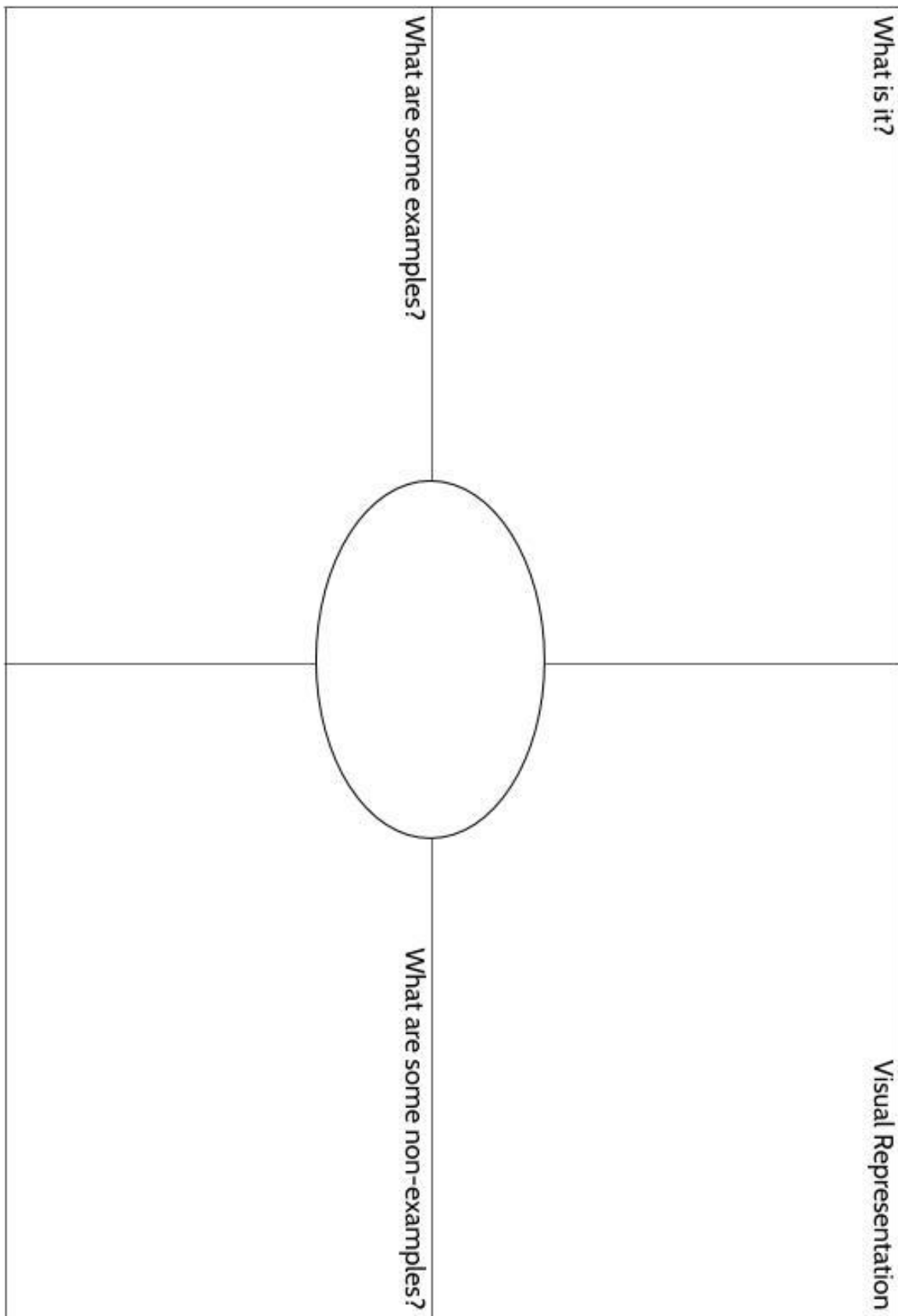
In order to learn math vocabulary, we need practice using words in different ways. In this activity, you will choose a few words from this packet that you want to practice, then you will complete a graphic organizer for each word. Look at the sample for the word *quotient* below.

To start, choose a word from the packet and complete the graphic organizer:

- **What is the definition of the word?** You can look at the vocabulary review on page 87 for help. Write the definition in your own words to really make the word yours.
- **Make a visual representation.** You can make a drawing or diagram that will help you remember what the word means.
- **What are some examples of the word you're studying?** Below you can see that there are examples of *quotients*, which are the answers to division problems.
- **What are some non-examples of this word?** These are things that are **not** the word you're studying. For example, 24 is **not** the quotient of 4 divided by 6.

<p>What is it?</p> <p>A quotient is the result of dividing one number by another. It is the answer to a division question.</p>	<p>Visual Representation</p> 
<p>What are some examples?</p> <p>15 divided by 3 equals 5</p> <p>$66 \div 6 = 11$</p> <p>$63/18 = 3.5$</p> <p>5, 11 and 3.5 are quotients in these calculations.</p> <p>population \div area = density</p>	<p>What are some non-examples?</p> <p>4 times 6 equals 24</p> <p>$18 + 5 = 23$</p> <p>$17 - 2.5 = 14.5$</p> <p>$3.5 \times 18 = 63$</p>

The Power of Exponents (Part 1)



The Power of Exponents (Part 1)

What is it?		Visual Representation
What are some examples?		What are some non-examples?

Sources

Sallay, I. (2020). Find the Factors. findthefactors.wordpress.com (Section: Multiplication Practice)