APPLICATIONS OF ALGEBRA

DEALING WITH

AUTOMOBILES

FOR USE IN CONNECTION WITH THE FIRST YEAR'S WORK IN ALGEBRA

BY

THIRMUTHIS BROOKMAN AND OTHERS

MEMBERS OF THE TEACHERS CLASS IN APPLIED MATHEMATICS
UNIVERSITY OF CALIFORNIA, SUMMER SESSION, 1913

REVISED 1914, 1915

CHARLES SCRIBNER'S SONS

NEW YORK CHICAGO BOSTON

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PREFACE

The purpose of this booklet is to vitalize first-year algebra by applying it to objects with which the pupils may readily become familiar in daily life.

Among the many machines whose operations can be fairly comprehended by those whose knowledge is limited to elementary algebra, none seem of more far-reaching interest and importance than the automobile. These pages, therefore, develop the simpler algebraic formulas used in the operation of automobile engines, in the transmission of speed, and in problems dealing with automobiles on the road.

The algebra used in the solution of these applications is the linear equation, direct proportion, and a limited knowledge of pure quadratics. The applications of elementary algebraic principles herein are similar to those developed throughout the first year's work in algebra in Brookman's *Practical Algebra for Beginners.* It is expected that such problems of real life, which are of a nature to enlist the ready interest of many pupils, will replace the difficult manipulations of abstract symbols included in several of the current texts, and will also give more real significance to the algebraic equation. It is hoped that this booklet will encourage the beginner to enter into the study of algebra with alertness and keen interest, because he realizes that it gives him mastery over the practical formulas needed in actual experience.

The writers wish to acknowledge their indebtedness to all who have given them suggestions and practical information, and especially to Mr. Alden McElrath of the Oakland headquarters of the Cadillac Motor Company.

San Francisco, June, 1916.

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CHAPTER I

AUTOMOBILE ENGINES

1. General Description. The relation of the different parts of an automobile may be seen in the following picture of one of the latest types of machines. This description, with slight variations, applies to all popular makes of cars. The parts italicized in the description should be located in the following diagram.

The power which runs the car is generally obtained from gasolene or electricity. This book will consider only those machines which are run by gasolene. The motive power of such machines is generated in *cylinders* located in front of the car. The movement of the piston in each cylinder helps to turn the crank-shaft, which is beneath the cylinders. (The crank-shaft does not appear in the drawing.)

The crank-shaft and the *fly-wheel* (usually behind the engine) are securely connected and so revolve together. Into the hollowed portion of the fly-wheel is fitted a *cone clutch*, by means of which the motion of the fly-wheel may be imparted to the machine. When the cone clutch is

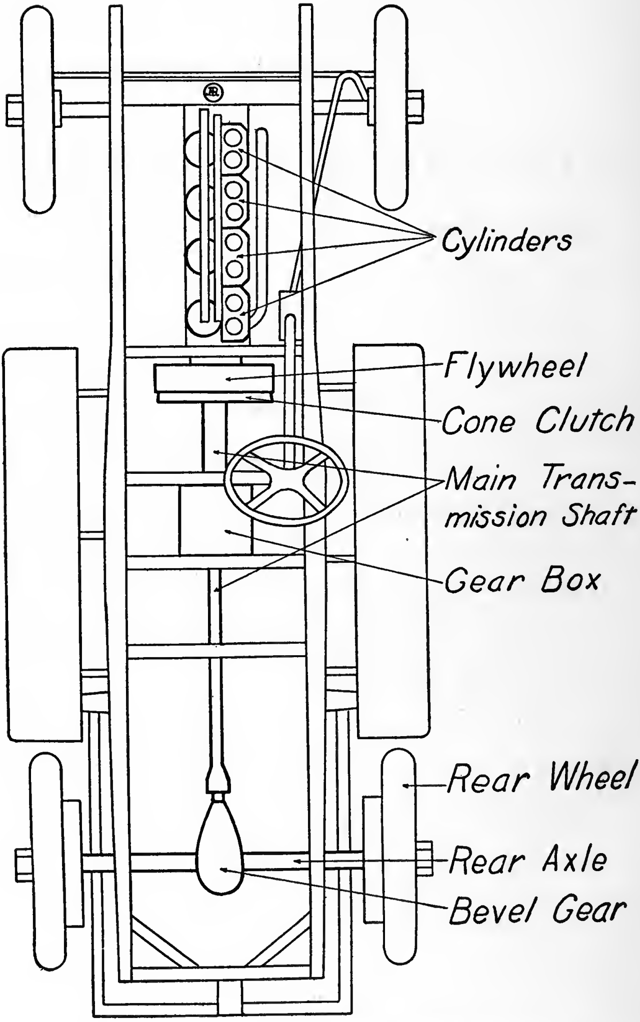
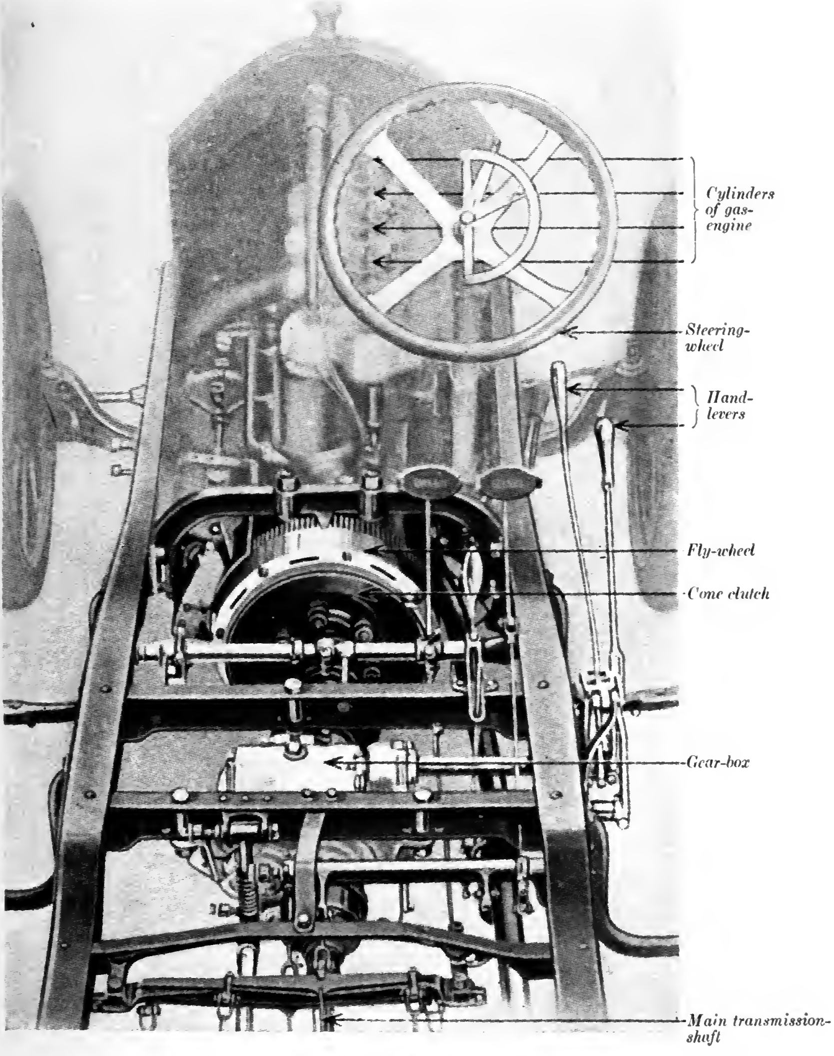


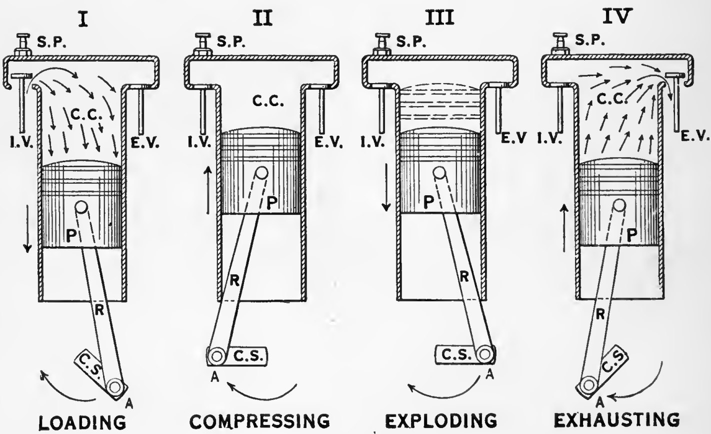
DIAGRAM SHOWING OPERATING MECHANISM



CADILLAC OPERATING MECHANISM

disconnected or the hand-lever is in neutral position the engine may run while the automobile is standing still. This is called "idling." From the cone clutch extends the *main transmission-shaft* in two parts through the *gear-box* to the *bevel-gears*, which turn the rear axle of the machine. Some machines have the multiple disk or some other type of clutch in place of the cone. (If possible pupils should see the operating mechanism of several different automobiles.)

2. The Gasolene-Engine. The engine is the most vital and also the most intricate part of the automobile, and an understanding of its construction and workings is of the utmost importance. Most *motor*-cars are equipped with engines of four, six, or eight cylinders, while the simplest form of engine has but one.



CYLINDER SHOWING FOUR POSITIONS OF PISTON

The cylinder is closed at the top and fitted with a *piston* (*P*) connected with a *rod* (*R*) to the *crank-shaft* (*C.S.*). The accompanying picture of one type, the four-cycle gas-engine, shows four positions of the *piston*. Above the piston is the *combustion chamber* (*C.C.*), where there are two valves, an *inlet valve* (*I.V.*) and an *exhaust valve* (*E.V.*). Find these parts in the accompanying illustration.

I, *II*, *III* and *IV* show four different positions of the piston in a single cylinder.

In *I*, if the machine is in motion, the piston is approaching the bottom of the cylinder. As the piston moves downward the inlet valve (*I.V.*) opens to admit a mixture of gasolene-vapor and air, the explosion of which is to furnish the motive power. This valve closes automatically when the piston is near the bottom of the stroke.

In *II* the piston is approaching the top of the cylinder and compressing the gas in the combustion chamber to a fraction of its former volume.

In *III* the dotted line shows the highest position which the piston reaches. Near this point an electric spark from the spark-plug (*S.P.*) explodes the compressed gas in the cylinder and the piston is immediately forced downward by the expansion of the gas.

In *IV* the piston has again reached its lowest position, and as it moves upward the exhaust valve (*E.V.*) opens and the piston forces out the spent gas. As the piston reaches the top the exhaust valve closes, the inlet valve opens, the piston returns again to the position shown in *I*, and the cycle is completed.

In order to obtain increased power for running the machine, the one-cylinder engines have been replaced by those containing more cylinders. As the number of cylinders increases, the number of explosions in the engine to every revolution of the fly-wheel also increases and produces a more continuous power and a more smoothly running engine. However, the ratio between the number of explosions in one cylinder and the revolutions of the crank-shaft remains the same. In the four-cylinder car four explosions, one in each cylinder, cause two revolutions of the fly-wheel; likewise, in the six-cylinder car, six explosions, one in each cylinder, cause only two revolutions of the fly-wheel.

Questions

1. As the piston passes from one extreme position to another show the number of degrees through which the point A on the crank-shaft passes.

2. As the piston completes the four phases of one cycle, show that point A on the crank-shaft passes through 720°.

3. During the four phases of one cycle how many revolutions does the fly-wheel make? How many explosions does the one-cylinder engine make?

4. How many revolutions would the fly-wheel make for 10 explosions in a one-cylinder engine? How many for 120 explosions?

5. When the fly-wheel turns 40 times, how many explosions occur in the cylinder?

3. Problems on a One-Cylinder Engine. In the following problems consider the engine as having one cylinder only.

1. (a) If a gas-engine makes 420 explosions per minute, how many revolutions will the fly-wheel make in the same time?
(b) How many revolutions will the fly-wheel make in 5 minutes?

2. If the fly-wheel of a gas-engine makes 1200 revolutions per minute, how many explosions will there be?

3. (a) If a gas-engine of a motor-cycle makes 484 explosions per minute, and the fly-wheel turns 11 times while

the rear wheel turns 3 times, how often will the rear wheel turn in a minute?

(b) If the circumference of the rear wheel of a motor-cycle is 8 ft., how far does it travel in a minute?

(c) How long will it take to travel half a mile?

4. (a) The circumference of the rear wheel of a motor-cycle is $7\frac{1}{2}$ ft. If the rear wheel makes 3 revolutions to 11 of the fly-wheel, how many revolutions will the fly-wheel make in travelling one-half mile?

(b) How many explosions will the engine make in travelling 3 miles?

5. (a) The diameter of the rear wheel of a motor-cycle is 2.5 ft. The fly-wheel turns 55 times while the rear wheel is turning 16 times. How many feet will the motor-cycle have moved when the engine has made 2000 explosions?

(b) If the fly-wheel makes 1500 revolutions per minute, what will be the speed in miles per hour?

4. Horse-Power of Gas-Engines. The explosion in the cylinder produces a *mean effective pressure* of from 40 to 70 pounds per square inch in all directions.

To obtain the number of foot-pounds of energy developed by a single explosion in a cylinder, three things must be considered:

P, the average pressure of the gas in pounds per square inch.

a, the area of the piston in square inches.

l, the length of the stroke in inches.

If d is the diameter of the piston or cylinder, the area of the piston is obtained by the formula

$$a = \frac{\pi d^2}{4} \text{ or } a = \frac{3.1416d^2}{4} = .7854d^2.$$

Since the area of a circle equals the product of π and the square of the radius, explain how this formula is obtained.

5. Problems on Piston Pressure.

1. If the diameter of a piston is 4 in., what is the area?

2. Find the area of a piston whose diameter is 5 in.

3. Find the diameter of a piston whose area is 19.635 sq. in.

4. What is the diameter of a piston if its area is 15.9 sq. in.?

5. The total force F pressing against the end of a piston equals the product of the area in square inches by the pressure per square inch. This may be expressed by the formula $F = Pa$, in which F is the total number of pounds; also by the formula

$$F = \frac{P\,3.1416\,d^2}{4} \text{ or } F = \frac{P\pi d^2}{4}.$$

Explain how this formula is obtained.

6. If the pressure in a cylinder is 50 lbs. per sq. in. and the area of the piston is 16.4 sq. in., what is the total force (F) pressing against the piston?

7. If the pressure (P) is 55 lbs. per sq. in. and the diameter of the piston 5 in., what is the total force (F) pressing against the piston?

8. What is the total force against a piston during the power or explosion stroke of an engine, if the diameter of the cylinder is 4.5 in. and the average pressure is 65 lbs. per sq. in.?

9. (a) Find the area of the piston if a pressure of 60 lbs. per sq. in. produces a total pressure of 756 lbs.
(b) Find the diameter of the piston.

10. A pressure of 80 lbs. per sq. in. on a piston produces a total force of 570.8 lbs. What is the diameter of the piston?

The total amount of energy generated during one explosion stroke may be expressed in *inch-pounds;* 820 in.-lbs. will lift 820 lbs. through 1 in. or 410 lbs. through 2 in., etc.

Describe other illustrations of work done by inch-pounds. The total amount of energy (E) is the product of the total force (F) pressing against the piston and the length (l) through which the piston acts. If, during one explosion stroke, a total average force of 2500 lbs. is exerted through a distance of 6 in., the total amount of energy generated is 15,000 in.-lbs., since $2500 \times 6 = 15{,}000$.

11. (a) How many inch-pounds are developed if $F = 1900$ and $l = 8$ in.?

(b) Explain the formula $E = Fl$.

(c) Since $F = Pa$, explain how the formula $E = Fl$ becomes $E = Pla$.

(d) 900 in.-lbs. lifts 900 lbs. through 1 in., or through $\frac{1}{12}$ of a foot; hence 900 in.-lbs. = 75 ft.-lbs. Why?

(e) Explain the formula $E = \frac{Pla}{12} = \frac{Pl\pi d^2}{12 \times 4} = \frac{Pl\pi d^2}{48}$, in which E denotes the number of foot-pounds of energy developed during one explosion stroke.

12. How many foot-pounds of energy are generated by one explosion in an engine if the diameter of the cylinder is 4 in., the length of the stroke (l) is 5 in., and the average pressure (P) is 62.5 lbs. per sq. in.?

13. If d is 5.5 in., l is 4.6 in., P is 65 lbs. per sq. in., how many foot-pounds of energy are generated during each explosion?

14. If the area (a) of the piston of an engine is 18 sq. in., the length of the stroke 5 in., and the energy developed at each explosion 435 ft.-lbs., what is the mean average pressure (P)?

Find the value of the unknown in each of the following problems:

	PRESSURE	LENGTH	DIAM. OF PISTON	ENERGY (during one explosion)
				Foot-Pounds
15	50 lbs. per sq. in.	4 in.	4.5 in.	x
16	x " " " "	5 "	4 "	251.328
17	60 " " " "	x "	4 "	345.576
18	50 " " " "	5 "	4.8 "	x
19	48 " " " "	4.8 "	x "	376.992

6. Formula for Energy per Minute.

If n = the number of revolutions of the crank-shaft per minute, then n = the number of revolutions of the fly-wheel per minute. Why? And $\frac{n}{2}$ = the number of explosions in a single cylinder per minute. Why?

Since E = the number of foot-pounds of energy developed during one explosion stroke and $E = \frac{Pla}{12}$, then $\frac{Pla}{12} \times \frac{n}{2}$ = the number of foot-pounds of energy developed in a single cylinder in one minute. Why?

Formula. Energy per minute, (per cylinder) $E = \frac{Pla}{12} \times \frac{n}{2} = \frac{Plan}{24}$.

Illustrative Problem

A one-cylinder gas-engine makes 420 explosions per minute, the inside diameter of the cylinder is 4 in., the length of the stroke is 5 in. Find the pressure per square inch of the piston if the engine develops 109,956 ft.-lbs. of energy per minute.

$E = 109{,}956$ ft.-lbs. per minute,

$l = 5$ in.

$a = \frac{\pi d^2}{4} = 4\pi = 12.5664$ sq. in. Why?

$n = 2 \times 420 = 840.$

Then the formula $E = \frac{Plan}{24}$

becomes $109{,}956 = \frac{P \times 5 \times 12.5664 \times 840}{24}$

or $2199.12P = 109{,}956$ and $P = 50$ lbs. per sq. in.

7. Problems on Revolutions of the Fly-Wheel. In the following problems n denotes the number of revolutions per minute of the fly-wheel, and E the number of foot-pounds developed in one cylinder per minute.

1. If the fly-wheel of a one-cylinder engine makes 400 revolutions per minute, the pressure (P) is 64 lbs. per sq. in., the length (l) is 4 in., and the area (a) is 16 sq. in., how many foot-pounds of energy are developed per minute?

2. The fly-wheel of a gas-engine makes 960 revolutions per minute, P is 70 lbs. per sq. in., and l is 4.5 in. What is the area of the piston if 158,400 ft.-lbs. of energy are developed per minute in a single cylinder?

Find the value of the unknown in each of the following problems, if E denotes the energy developed per minute in a single cylinder.

	P	l	a	n	E
3	66	5.6	14	1000	x
4	x	5.5	15	800	176,000
5	80	x	13.5	900	182,250
6	75	5	x	1200	243,750
7	70	5.2	18	x	300,300
8	72	4.4	20.5	1000	x
9	x	4.8	19.2	1500	345,600

If c equals the number of cylinders in a gas-engine the number of foot-pounds of energy (E) developed per minute in the gas-engine is expressed by the formula $E = \frac{Planc}{24}$. Explain.

10. A gas-engine has 4 cylinders, each having a diameter of 4 in. If the length of the stroke is 5 in., the average pressure on the piston is 60 lbs. per sq. in., and the number of revolutions of the fly-wheel per minute is 600, how many foot-pounds of energy are developed per minute?

11. A two-cylinder gas-engine develops 360,000 ft.-lbs. of energy per minute, A is 16 sq. in., l is 4.5 in., and n is 800 revolutions per minute. What is the average pressure (P) per square inch against each piston?

If E denotes the energy developed in the gas-engine, find x in the following problems:

	P	l	a	n	c	E
12	65	4.2	18	1000	4	x
13	70	x	15.5	1400	4	1,063,300
14	72	4.8	x	850	4	628,320
15	69	5	16	1300	x	1,196,000
16	74	5.3	17.5	900	8	x

8. Problems on Horse-Power. Let HP equal the horse-power of a gas-engine. Since 33,000 ft.-lbs. per minute is 1 horse-power, the horse-power of the engine is the number of foot-pounds developed per minute divided by 33,000.

If P = pressure in pounds per square inch,
l = length of stroke in inches,
a = area of piston in square inches,
c = number cylinders in engine,
E = energy during one explosion stroke in foot-pounds,

n = number of revolutions of the fly-wheel per minute,

$$\text{then } HP = \frac{E}{33{,}000} = \frac{Planc}{24 \times 33{,}000} = \frac{Pl\pi d^2nc}{24 \times 4 \times 33{,}000}$$

1. How many horse-power are developed by a four-cylinder engine if P is 60 lbs. per sq. in., l is 5 in., a is 16.5 sq. in., and n is 1000 revolutions per minute?

2. A gas-engine has four cylinders. What is the average pressure (P) per square inch if l is 4.8 in., a is 17.6 sq. in., n is 1350 revolutions per minute, and the horse-power is 48?

3. How many revolutions per minute will the fly-wheel of a four-cylinder gas-engine make while developing 40.5 horse-power, if P is 66 lbs., l is 4.5 in., and a is 20 sq. in.?

Find x in the following problems:

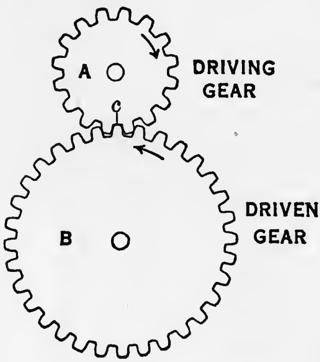
	P	l	d	n	c	HP
4	72	5.5	4	1250	4	x
5	80	5.5	5	x	6	65.45
6	x	5	4	1400	4	31
7	77	x	4.8	1360	4	50.26
8	71	5.5	x	1000	4	40.3
9	68.5	4.8	5	1450	4	x
10	72	5	4	1500	x	68.5

The California State Automobile Registration Board during 1915 used the formula $HP = .224(d + l)dc$. By this formula find the horse-power in each of the problems 4, 5, 6, and 9 above. The formula used by the State Board in 1916 is $HP = \frac{2}{5}d^2c$. By this formula find the horse-power in problems 4, 5, 6, and 9.

CHAPTER II

TRANSMISSION OF SPEED

9. Gears in Mesh. The accompanying figure shows *two gears in mesh*, the smaller gear, or pinion (A), turns the driven gear (B). It is not difficult to see that the driving-gear rotates in one direction while the driven gear rotates in the opposite direction.



(a) Count the number of teeth in each gear.

(b) When the driving-gear (A) turns once, with how many teeth of the driven gear (B) has it been in mesh?

(c) How many times must the point c on the driving-gear return to its position in order to put each tooth of B in mesh once, or to cause one complete revolution of B?

Let t represent the number of teeth in A,

t' represent the number of teeth in B,

r represent the number of revolutions in A,

r' represent the number of revolutions in B.

Show by counting that the following numerical ratios are true:

1. $\frac{t}{t'} = \frac{16}{32} = \frac{1}{2}$. This equation is read: "The number of teeth in A *is to* the number of teeth in B *as* 16 *is to* 32, or as 1 to 2."

2. Show by counting the revolutions that

$$\frac{r}{r'} = \frac{2}{1} \text{ and } \frac{r'}{r} = \frac{1}{2}.$$

3. Since $\frac{t}{t'} = \frac{1}{2}$ and $\frac{r'}{r} = \frac{1}{2}$, then $\frac{t}{t'} = \frac{r'}{r}$, since the value of each ratio, $\frac{t}{t'}$ and $\frac{r'}{r}$, is $\frac{1}{2}$. This equation may be expressed by saying that the number of teeth in two gears in mesh is *inversely proportional* to the number of revolutions they make in a given time.

By clearing of fractions the equation $\frac{t}{t'} = \frac{r'}{r}$ becomes $tr = t'r'$.

In the accompanying figure $t = 16$, $r = 2$, $t' = 32$, $r' = 1$; the equation $tr = t'r'$ becomes $16 \times 2 = 32 \times 1$.

This equation may be expressed by saying that the number of revolutions of the driving-gear multiplied by the number of its teeth equals the number of revolutions of the driven gear multiplied by the number of its teeth.

10. Problems on Gears.

1. A driving-gear with 12 teeth makes 200 revolutions per minute. How many revolutions per minute will be made by the driven gear which has 24 teeth?

2. A driving-gear with 20 teeth revolves 180 times per minute. How many revolutions per minute will the driven gear make if the number of its teeth is 30? How many if the number of its teeth is 24?

3. A gear having 16 teeth is making 240 revolutions per minute. How many teeth has a second gear in mesh with the first if it is making 120 revolutions per minute? How many teeth would the second gear have if it were making 160 revolutions per minute?

Complete the following table by filling in the blank spaces.

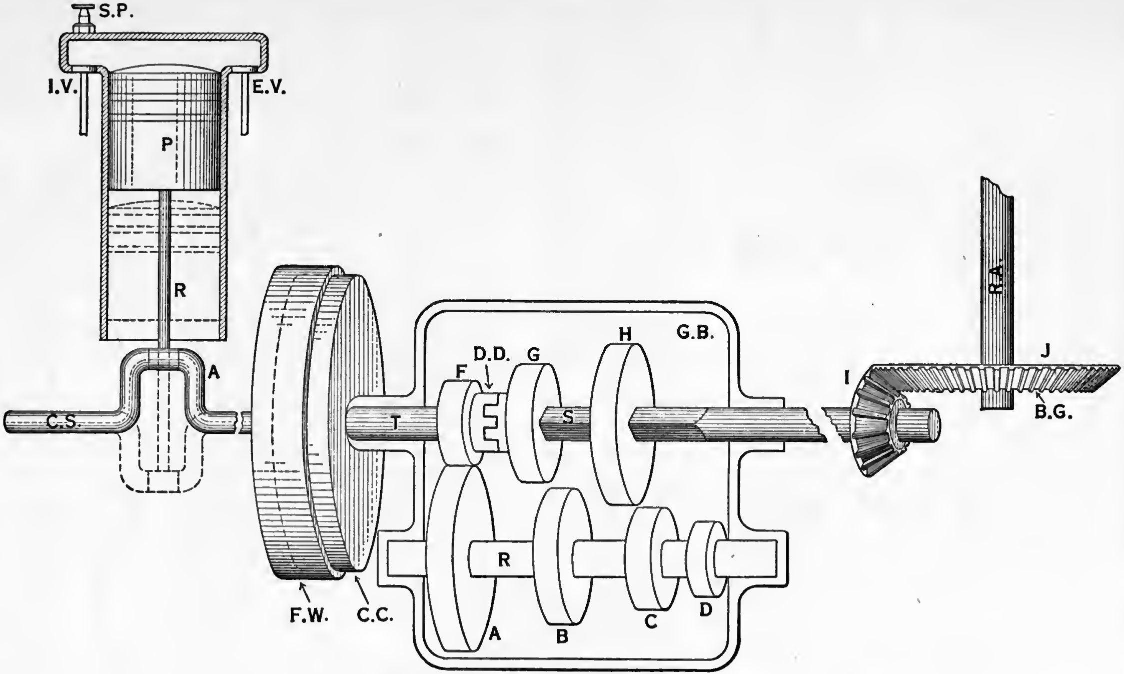
	DRIVING-GEAR		DRIVEN GEAR	
	NO. OF REV.	NO. OF TEETH	NO. OF REV.	NO. OF TEETH
4	180	16	...	20
5	360	12	540	..
6	750	..	600	25
7	...	22	462	28
8	384	27	...	32
9	155	..	85	31
10	620	13	260	..
11	...	24	288	31
12	363	15	...	55
13	275	14	78	..

11. High-Speed Transmission. The motion from the engine which turns the crank-shaft (*C.S.*) and fly-wheel (*F. W.*) reaches the rear axle by means of the main transmission-shaft, *T*.

The front part of the main transmission-shaft is connected with the engine crank-shaft by means of the cone clutch (*C.C.*), the two conical surfaces of which are held firmly together by springs, except when forced apart by the driver pressing the clutch pedal, as in the figure showing low speed (page 30). With this exception the front part of the transmission-shaft (*T*) revolves whenever the engine runs. The rear part (*S*) communicates its motion through the bevel pinion and gear (*I* and *J*) to the rear axle and the rear wheels.

The accompanying figure shows the *high-speed transmission* which gives the greatest possible car speed for a given speed of the engine. This manner of connection is also called the **direct drive** (*D.D.*).

One part of the clutch *DD* is fixed to the gear *G*. When this is brought into its extreme forward position, as shown in the figure, the clutch *DD* engages and *T* and *S* rotate as



HIGH SPEED OR DIRECT DRIVE

one shaft. This manner of connection is called the *direct drive.* It is also called *high-speed transmission,* since it gives the greatest possible car speed for a given speed of the engine. The direct-drive transmission does not use the counter-shaft R, but because gear F is in constant mesh with gear A the counter-shaft turns ready for use when intermediate, low, or reverse speeds are desired.

Without changing the position of the gears the speed of the car may be regulated to some extent by increasing or decreasing the amount of gasolene used in the engine, or by advancing or retarding the spark.

The following questions refer to the direct-drive position of the gears.

1. In this position which gears and shafts are rotating as the engine runs? Which are idling (*i. e.*, turning without transmitting power)?

2. What is the effect of disengaging the cone clutch?

3. What is the effect of stopping the explosions in the engine? What parts will continue to turn?

4. What is the effect of disengaging $D.D.$ when the engine is running and $C.C.$ is engaged?

5. With both clutches engaged, one turn of the crank-shaft makes how many turns of the pinion I?

12. Problems on High-Speed Transmission. In each of the following problems which concern four-cylinder engines the two clutches are connected to form the direct drive.

1. If a gas-engine makes 920 explosions per minute, how many times will the fly-wheel revolve per minute?

2. If the clutch is thrown in, how many times will the small pinion-gear at the rear of the main driving-shaft revolve per minute?

3. If the driving-pinion contains 13 teeth and is in mesh with a driven bevel-gear which contains 52 teeth, how many times will the driven gear turn when the driving-pinion turns once? when the driving-pinion turns 460 times?

4. If the fly-wheel makes 920 revolutions per minute, how many times will the rear axle turn if the bevel-gear ratio is 1 to 4? How far will the car travel in a minute if the circumference of the rear wheel is 9 ft.?

Complete the following table in problems 5 to 15 by filling in the blanks. Consider the bevel-pinion as having 13 teeth, the bevel-gear as having 52 teeth, and the circumference of the rear wheel as 9 ft.

	NO. REV. OF FLY-WHEEL	NO. REV. OF DRIVING-PINION	NO. REV. OF BEVEL-GEAR	NO. REV. OF REAR AXLE	NO. FEET TRAVELLED PER MIN.
5	900	...	...	...	....
6	1000	...	...	...	....
7	1200	...	...	...	....
8	1280	...	...	...	....
9	....	840	...	...	....
10	....	...	325	...	....
11	....	...	275	...	....
12	....	...	...	310	....
13	....	...	...	290	....
14	....	...	...	...	2385
15	....	...	...	...	2655

16. If the speed limit in the country is 25 miles per hour, which of the preceding problems have rates which exceed the speed limit?

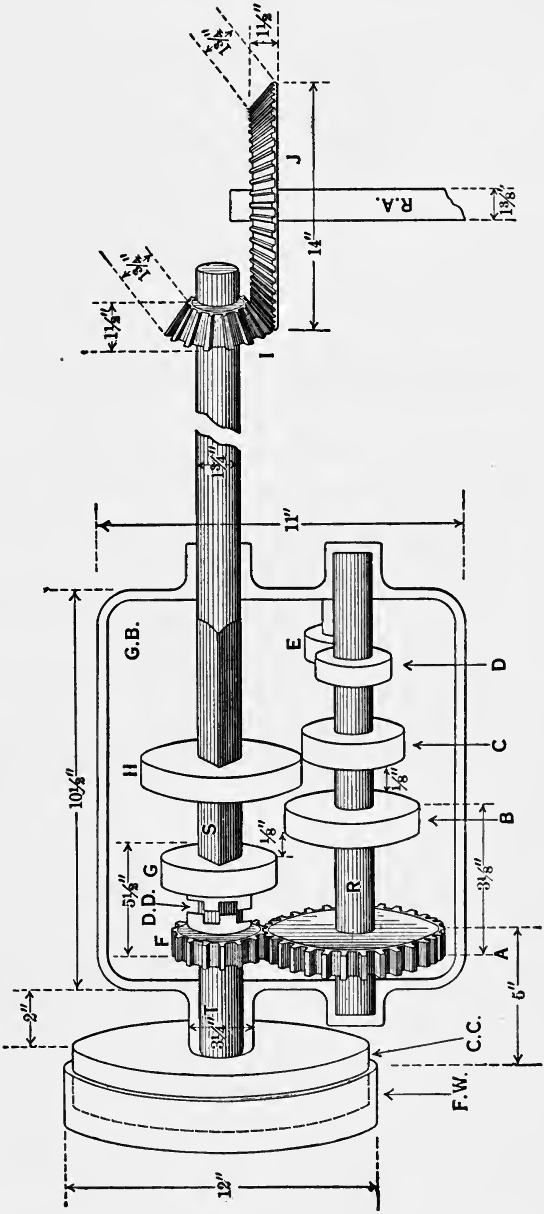
13. Gear-Box and Gears in Neutral. The purpose of the *gear-box* mechanism (*G.B.*) is to enable the two parts *T* and *S* of the transmission-shaft to be connected in either of four ways or to be entirely disconnected, the selection being made by the driver placing the hand-lever in one of five positions. When disconnected the lever and gear mechanism are said to be *neutral*, as in the figure. Show why shaft S does not rotate when T rotates. (Study $D.D.$) The four methods of connection are called *first* or *low speed*, *second* or *intermediate speed*, *third* or *high speed*, and *reverse speed*. The words *low* and *high* do not refer to the actual running-speed of the car, but to the ratio of the speed of the car to that of the engine, which is determined by the speed ratio of the two parts T and S of the transmission-shaft.

The front part T of the transmission-shaft carries the gear F and one part of the clutch $D.D.$ The other part of this clutch is fixed to the gear G. This clutch $D.D.$ is engaged only in the direct-drive or high-speed transmission when T and S rotate as one shaft. Gears G and H are carried upon the square part of shaft S so as to rotate with it, but may slide along it. It is by sliding G and H into different positions that the manner of connection of S and T is determined. The gears A, B, C, and D are fixed to the counter-shaft R.

In the preceding figure, the direct-drive clutch ($D.D.$) is disengaged, S and T being entirely disconnected. This is usually the case when the engine is running idle, *i. e.*, without driving the car. (The engine may be permitted to run idle by disengaging the cone clutch, whatever the connection of S and T may be, but this requires that the clutch pedal be forcibly held down by the driver.) This position is shown in the following figure for low-speed transmission. The car here cannot run until the driver releases the cone clutch.

1. Locate the following parts in the accompanying figure.

$F.W.$—Fly-wheel.
$C.C.$—Cone clutch.
T and S—Main transmission-shaft, front and rear parts.
$D.D.$—Direct-drive clutch.
$G.B.$—Gear-box.



GEARS IN NEUTRAL

I—Bevel-pinion.
J—Bevel-gear.
R.A.—Rear axle.
R—Counter-shaft.
A and *F*—Constant mesh gears.
B and *G*—Intermediate-speed gears.
C and *H*—Low-speed gears.
D and *E*—Reverse-speed gears (with *H*).

2. Which parts rotate when the cone clutch *C.C.* is disengaged?

3. Which parts rotate when the cone clutch *C.C.* is engaged and the direct-drive clutch *D.D.* disengaged and the gears are located as in the preceding figure?

4. When *C.C.* is engaged and *D.D.* disengaged, which parts rotate:

(a) When *B* and *G* are in mesh, as in figure showing intermediate speed?

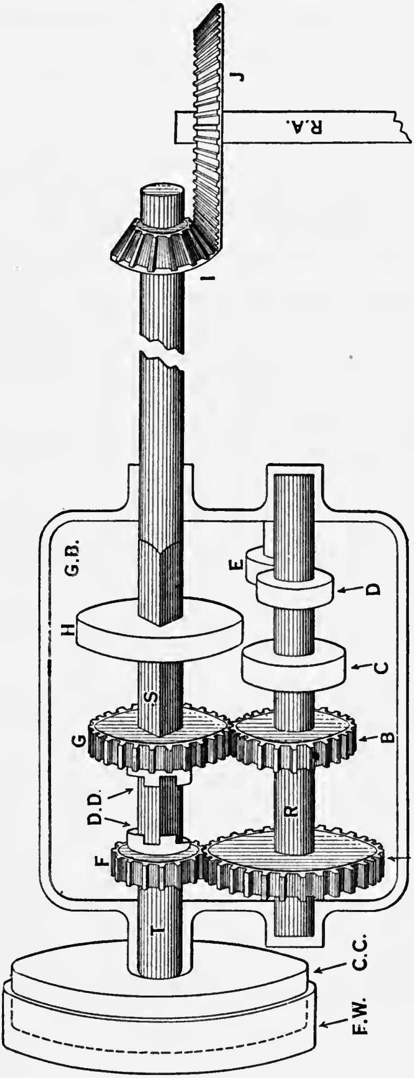
(b) When *C* and *H* are in mesh, as in figure showing low speed?

(c) When *E* and *H* are in mesh, as in figure showing reverse speed?

14. Intermediate Speed. To run an engine at an intermediate speed a counter-shaft (*R*) is used. On this shaft are four gear-wheels (*A*, *B*, *C*, and *D*) rigidly attached. On part (*T*) of the main transmission-shaft the gear-wheel *F* is firmly fixed and in constant mesh with the gear-wheel *A* on the counter-shaft *R*. When *T* rotates, the shaft *R* and all of the gear-wheels on it rotate also.

The section of the transmission-shaft *S* which is within the gear-box is square, except the bearings, one of which is within the hub of the gear *F*. The two gears *G* and *H* have square holes in their hubs that fit the square shaft *S*; thus when these gears revolve the shaft also revolves.

For the intermediate speed, the gear *G* is moved along *S* until it engages with *B*. The clutch *D.D.* is now "out," so



INTERMEDIATE SPEED

that T and S are not connected directly, but the motion of the fly-wheel is transmitted through the gears F, A, B, G, I, J to the rear wheel. Trace this transmission in the figure above.

Use the figure illustrating intermediate speed in answering the following questions. The gears in the figure have the following numbers of teeth:

F, 15	B, 28	I, 13
A, 30	G, 28	J, 52

(1) When F turns twice, how many times does A turn? Why?

(2) In this figure why does not G turn the same number of times as F?

(3) Why does gear B turn the same number of times as gear A?

(4) Why does gear G turn the same number of times as gear B?

(5) Why does pinion I turn the same number of times as gear G?

(6) Why does pinion I turn the same number of times as gear B?

(7) Why does pinion I turn the same number of times as gear A?

(8) Why does pinion I turn one-half as often as gear F?

(9) Why does pinion I turn one-half as often as the fly-wheel?

(10) In considering gears F and A, why is F the driving-gear and A the driven gear? In considering gears B and G which is the driving-gear, B or G?

Illustrative Problems

Let F, the first driving-gear, contain 17 teeth,
and A, the first driven gear, contain 31 teeth,
and B, the second driving-gear, contain 24 teeth,
and G, the second driven gear, contain 31 teeth.

Then if the fly-wheel turns 1800 times, how many times does pinion *I* turn?

Justify each of the following statements:

When the fly-wheel turns once, gear *F* turns once.

When the fly-wheel turns 1800 times, *F* turns 1800 times.

When gear *F* turns once, gear *A* turns $\frac{17}{31}$ times.

When gear *F* turns 1800 times, gear *A* turns $1800 \times \frac{17}{31}$ times.

When gear *A* turns once, gear *B* turns once. (See figure.)

When gear *A* turns $1800 \times \frac{17}{31}$ times, gear *B* turns $1800 \times \frac{17}{31}$ times. Why?

When gear *B* turns once, gear *G* turns $\frac{24}{31}$ times.

When gear *B* turns $1800 \times \frac{17}{31}$ times, gear *G* turns $1800 \times \frac{17}{31} \times \frac{24}{31}$ times.

So, when the fly-wheel turns 1800 times, *F* turns 1800 times, gears *A* and *B* each turn $1800 \times \frac{17}{31}$ times, and gear *G* and pinion *I* turn each $1800 \times \frac{17}{31} \times \frac{24}{31}$ times.

The number $1800 \times \frac{17}{31} \times \frac{24}{31}$ may be obtained directly by noticing its factors.

1800 is the number of revolutions of the fly-wheel,
17 is the number of teeth of the first driving-gear *F*,
24 is the number of teeth of the second driving-gear *B*,
31 is the number of teeth of the first driven gear *A*,
31 is the number of teeth of the second driven gear *G*.

Hence to find how many times the pinion turns, find the product of the number of revolutions of the fly-wheel, the number of teeth on the first driving-gear, and the number of teeth on the second driving-gear, and divide by the product of the number of teeth on the first driven gear and the number of teeth on the second driven gear.

The same principle may be stated as a formula:

Let r = number of revolutions of the fly-wheel,

Let t_1 = number of teeth in the first driving-gear.
(read *t* one)

Let t_2 = number of teeth in the second driving-gear.
(read t two)

Let t_1' = number of teeth in the first driven gear.
(read t one prime)

Let t_2' = number of teeth in the second driven gear.
(read t two prime)

Then the number of revolutions of the pinion is $\frac{r\, t_1\, t_2}{t_1'\, t_2'}$.

(a) Show how each factor of the number $1800 \times \frac{17}{31} \times \frac{24}{31}$ is represented in the number $\frac{r\, t_1\, t_2}{t_1'\, t_2'}$.

In the same way, if there are three driving-gears and three driven gears, the number of revolutions of the third driven gear is $r\, t_1\, t_2\, t_3 / t_1'\, t_2'\, t_3'$.

15. Problems on Intermediate Speed.

1. If the fly-wheel turns 1600 times, use the preceding formula to find the revolutions of the pinion when the gears have the following numbers of teeth:

F, 15	*B*, 28	*I*, 13
A, 30	*G*, 28	*J*, 52

Use the formula to complete the following table:

	FLY-WHEEL	DRIVING-GEARS			DRIVEN GEARS			REAR WHEEL
	NO. OF REV.	NO. OF TEETH			NO. OF TEETH			NO. OF REV.
		F	*B*	*I*	*A*	*G*	*J*	
2	10571	17	24	15	31	31	55	....
3	.....	17	24	15	31	31	55	2448
4	10571	17	..	15	31	31	55	867
5	21142	17	13	15	31	..	55	1326
6	528	18	28	15	36	28	55	....
7	5500	18	..	15	36	36	55	375
8	.....	18	18	15	36	36	55	72

9. (a) How many times will the pinion I turn while the fly-wheel makes 40 revolutions when the number of teeth is as follows:

$t_1 = 15$	$t_2 = 28$	$t_3 = 13$
$t_1' = 30$	$t_2' = 28$	$t_3' = 52$

(b) Show from the figure why pinion I is named t_3 and gear J is named t_3'.

(c) When t_3 turns once, how many times does t_3' turn?

(d) How many times does the bevel-gear turn when the pinion turns 20 times?

(e) How many times does the rear wheel turn when the fly-wheel turns 40 times?

(f) Explain the following from the figure:

When the fly-wheel turns once the pinion turns $\frac{1}{2}$ time.

When the pinion turns once the bevel-gear turns $\frac{1}{4}$ time.

When the pinion turns $\frac{1}{2}$ time the bevel-gear turns $\frac{1}{2} \times \frac{1}{4}$ time.

When the fly-wheel turns once the bevel-gear turns $\frac{1}{8}$ time.

So when the fly-wheel turns once the rear wheel turns $\frac{1}{8}$ time.

Trace from the figure the development of the following ratio, which is called the *final-gear ratio.*

$$\frac{\text{number of revolutions of the rear wheel}}{\text{number of revolutions of the fly-wheel}} = \frac{1}{8}.$$

10. (a) When the fly-wheel turns 1200 times a minute, how many revolutions does the rear wheel make?

If n = the number of revolutions of the fly-wheel per minute,
r = final gear ratio,
then nr = the number of revolutions of the rear wheel. Illustrate.

(b) When the fly-wheel turns 1200 times a minute and the circumference of the rear wheel is 9 ft., how far does the machine travel in a minute?

If nr = the number of revolutions of the rear wheel
and c = the circumference of the rear wheel in feet,
then nrc = the number of feet travelled by the machine in a minute. Explain.

(c) When the fly-wheel turns 1200 times a minute and the circumference of the rear wheel is 9 ft., how far does the machine travel in 25 minutes on the intermediate speed?

If d = the distance in feet,
and m = the number of minutes travelled,
explain the formula, $d = nrcm$.

The total number of feet travelled by an automobile is expressed by the product of the number of revolutions of the fly-wheel per minute, the given gear ratio, the circumference of the rear wheel in feet, and the number of minutes travelled.

In the following set of problems the number of teeth on the gears are the same as those given in 9(a), preceding, which make the final gear ratio $\frac{1}{8}$. The gears are set at intermediate speed.

11. If the fly-wheel of an automobile makes 840 revolutions per minute and the circumference of the rear wheel is 8 ft., how many feet will the car travel in 10 minutes?

12. The fly-wheel makes 960 revolutions per minute, and the circumference of the rear wheel is $8\frac{1}{2}$ ft. How far will the car travel in 5 minutes?

13. How many revolutions per minute will the fly-wheel make if the car travels one mile in 6 minutes and the circumference of the rear wheel is 8 ft.?

14. A motor-car whose rear wheel has a circumference of $8\frac{1}{4}$ ft. travels 2 miles in 10 minutes. How many revolutions per minute does the fly-wheel make?

15. How many minutes will it take an auto to travel 2 miles if the circumference of the rear wheel is 8 ft. and the fly-wheel makes 1056 revolutions per minute?

16. How long will it take a car to run 3 miles if the fly-wheel makes 880 revolutions per minute and the circumference of the rear wheel is 8 ft.?

17. What must the circumference of the rear wheel be if the fly-wheel makes 880 revolutions per minute and the car goes 3400 ft. in 4 minutes?

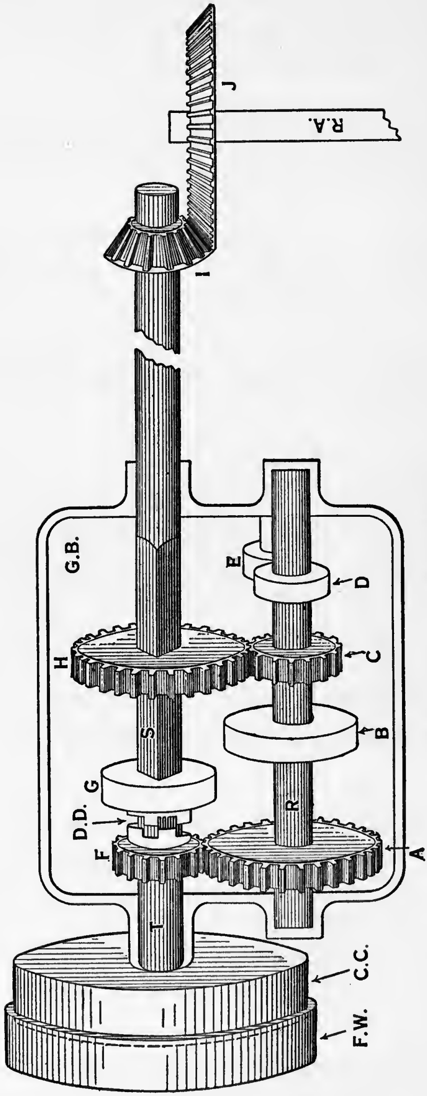
18. A car travelled $3\frac{1}{2}$ miles in 16 minutes while the fly-wheel made 1140 revolutions per minute. What was the circumference of the rear wheel?

16. Problems on Low Speed. To set the gears for low speed, the driver, by means of the hand-lever, slides gear *H* into mesh with *C*. Gear *G* and clutch *D. D.* are now in the same position as in neutral, both being disconnected. Thus the motion of the fly-wheel is transmitted through the gears *F*, *A*, *C*, *H*, *I*, and *J* to the rear wheel. Trace this transmission in the figure. Notice that the cone clutch is open and must be closed before the car will move.

Answer the following questions, the gears being set at low speed:

1. If *F* has 15 teeth, *A* 30, *C* 15, *H* 30, *I* 13, and *J* 52, how many revolutions will *F* make while the fly-wheel makes 80? How many will *A* make? *C*? *H*? *I*? *J*? How many revolutions will the rear wheel make? What is the ratio of the number of revolutions that the rear wheel makes to the number that the fly-wheel makes, or what is the final gear ratio?

2. In the following problems use the formula $d = nrcm$ and the low-speed ratio $\frac{1}{16}$. Explain how this ratio is obtained.



LOW SPEED

3. How many revolutions per minute will the fly-wheel make if the circumference of the rear wheel is $9\frac{1}{2}$ ft. and the car travels 5890 ft. in 10 minutes?

4. If an auto travels 2960 ft. in 4 minutes and the fly-wheel makes 1280 revolutions per minute, what is the circumference of the rear wheel?

5. In how many minutes will a car run a mile when the fly-wheel is making 1100 revolutions per minute and the circumference of the rear wheel is 8 ft.?

6. A machine is delayed by a flock of sheep for three-fourths of an hour, making $1\frac{1}{2}$ miles. How many times does the fly-wheel turn per minute if the circumference of the rear wheel is 8 ft.?

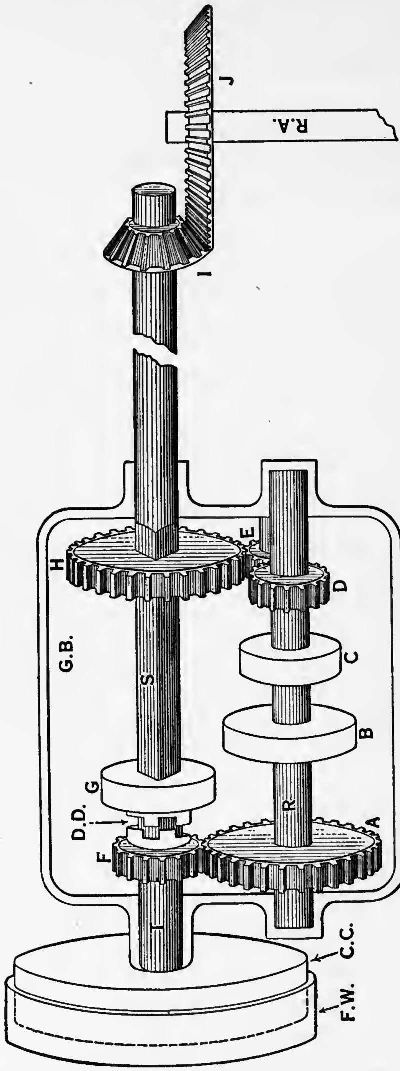
17. Reverse Speed. In order to drive the car backward, the pinion *I* must turn in the opposite direction to that which causes forward motion of the car. This requires that *S* and *T* must be so connected as to turn in opposite directions. This is accomplished by sliding the gear *H* into mesh with *E*, which is in constant mesh with *D*. Gear *G* and clutch *DD* remain disengaged.

(1) If the fly-wheel turns counter-clockwise, then *D* turns clockwise. In which direction does pinion *I* turn?

Trace the following from the appropriate drawings:

(2) During *low speed*, if the fly-wheel turns counter-clockwise, then

F turns counter-clockwise on main transmission-shaft *T*;
A turns clockwise (in mesh with *F*);
C turns clockwise (on counter-shaft *R*);
H turns counter-clockwise (in mesh with *C*);
the pinion turns counter-clockwise (same direction as *H*), and the rear axle turns the car *forward*.



REVERSE SPEED

(3) During reverse speed. If the fly-wheel turns counter-clockwise, then
F turns counter-clockwise (on main transmission-shaft);
A turns clockwise (in mesh with *F*);
C turns clockwise (on counter-shaft *R*);
E turns counter-clockwise (in mesh with *D*);
H turns clockwise (in mesh with *E*);
Pinion *I* turns clockwise (same direction as *H*);
and the rear axle turns the car backward (since, when pinion *I* turned counter-clockwise, the car went forward).

CHAPTER III

AUTOMOBILES IN MOTION

18. Road Problems.

1. If *F* has 15 teeth, *A* 30, *D* 12, *E* 12, *H* 30, *I* 13, and *J* 52, what is the final reversing-gear ratio?

2. How long will it take a car to back 180 ft. with the fly-wheel turning 400 times per minute if the final gear ratio is $\frac{1}{20}$ and the circumference of the rear wheel is 9 ft.?

3. How many feet per minute will an auto make on the reverse speed if the fly-wheel makes 500 revolutions per minute, the gear ratio is $\frac{1}{20}$, and the circumference of the rear wheel is 8 ft.? What will be the rate in miles per hour?

4. A man wishing to find the reversing-gear ratio of his car sent it backward 85 ft. in 20 seconds while the fly-wheel was turning at the rate of 480 times per minute. What was the gear ratio if the circumference of the rear wheel was $8\frac{1}{2}$ ft.?

5. If the fly-wheel of a car revolves 1100 times per minute, its gear ratio is $\frac{3}{22}$, and the circumference of the rear wheel is $9\frac{1}{2}$ ft., how many feet will it travel in 5 minutes?

6. If the number of revolutions of the fly-wheel is 900, the gear ratio is $\frac{3}{22}$, and the auto travels 5400 ft. in 5 minutes, what is the circumference of the rear wheel?

7. How many minutes will it take an automobile to travel 5400 ft. up a grade if the fly-wheel makes 880 revolutions per minute, the low gear ratio is $\frac{3}{44}$, and the circumference of the rear wheel is 9 ft.?

8. What must be the gear ratio of a car if it travels 12,825 ft. in 5 minutes when the number of revolutions of the fly-wheel is 1045 per minute and the circumference of the rear wheel is 9 ft.?

9. How many hours will it take a car to travel from San Francisco to Sacramento (94 miles) if its rate is 1215 ft. per minute?

10. How many hours will it take an automobile travelling 1320 ft. per minute to go from Santa Barbara, California, to Carson City, Nevada (650 miles)?

11. How many feet per minute must a motor-car travel in order to get from San Diego to San Bernardino (153 miles) in $4\frac{1}{2}$ hours. What will its rate be in miles per hour?

12. What is the distance from Berkeley to Yosemite Valley if an automobile travelling at the rate of 880 ft. per minute can make the distance in $22\frac{1}{12}$ hours?

13. If the fly-wheel of a machine makes 990 revolutions per minute, the gear ratio is $\frac{3}{22}$, the distance travelled is 4 miles in $19\frac{5}{9}$ minutes, what must be the circumference of the rear wheel?

14. A car travels from Salem to Portland, Oregon, at the rate of 14 miles per hour and returns at the rate of 21 miles per hour, making the trip in $6\frac{1}{3}$ hours. What is the distance between the two cities?

15. A machine running between Everett and Tacoma, Washington, averaged 14 miles per hour going and $24\frac{1}{2}$ miles per hour returning, making the trip in $8\frac{1}{4}$ hours. Find the distance between the two places.

16. A car averages $13\frac{1}{2}$ miles per hour for 7 hours. If one gallon of gasolene will carry the car $11\frac{1}{2}$ miles, how many gallons will be used on the trip?

17. If it requires one gallon of gasolene to run a car $11\frac{1}{2}$ miles, how many gallons will be required to run the car from San Francisco to Los Angeles (472.2 miles)? Find the cost of the gasolene at 15 cents per gallon.

18. How many revolutions of the fly-wheel are made per minute if the car goes $13\frac{1}{2}$ miles per hour, the gear ratio is $\frac{3}{22}$, and the circumference of the rear wheel is 9 ft.?

19. How many revolutions per minute will be made by the fly-wheel of a motor-car travelling from Long Beach to Los Angeles (21 miles) in 42 minutes, if the gear ratio is $\frac{3}{11}$ and the circumference of the rear wheel is 8 ft.?

20. In a Cadillac car gear F has 17 teeth, A 31, B 24, G 31, C 17, H 31, D 13, E 13, I 15, and J 55.

(a) The final gear ratio for direct drive, or high speed, is $\frac{1}{x}$. Find x. (See Section 15.)

(b) Find the gear ratio for intermediate speed.

(c) Find the gear ratio for low speed.

(d) Find the gear ratio for reverse speed.

21. The fly-wheel of an auto-car makes 900 revolutions per minute, the gear ratio is $\frac{3}{11}$, the diameter of the rear wheel is 3 ft. Find the distance the car travels in 10 minutes.

22. A machine with intermediate-speed gear ratio $\frac{8}{69}$ travels 1093 ft. per minute. How many revolutions per minute is the fly-wheel making if the diameter of the rear wheel is 36 in.?

23. A motor-car runs forward with high gear ratio $\frac{3}{11}$ for 1 minute; the fly-wheel turns 800 times per minute, and the circumference of the rear wheel is 9 ft. How many minutes will it take to back up to the starting-place, with the reverse gear ratio $\frac{1}{20}$ and the fly-wheel revolving at the same rate as before?

It has been found by trial that on a level macadamized road, in order to keep a car in motion, it requires an average force or pull of 25 lbs. for each 1000 lbs. of the weight of the car.

If F = average force required to keep the car in motion,
and W = total weight of the car in pounds,
then $\frac{F}{W} = \frac{25}{1000} = \frac{1}{40}$, or $F = \frac{W}{40}$.

(In the following problems the resistance of the air is neglected.)

The number of foot-pounds of energy necessary to keep the car moving depends not only upon the weight of the car but also upon its speed, which should be expressed in feet per minute.

If S is the speed in miles per hour,
then $\frac{S}{60}$ is the speed in miles per minute,
and $\frac{5280\,S}{60}$ or $88\,S$ is the speed in feet per minute. Why?

The number of foot-pounds of energy per minute used by a travelling car is the product of force and speed, or

$$E = FS = \frac{W}{40} \times 88\,S = \frac{11\,WS}{5}$$

Since one horse-power is 33,000 ft.-lbs. per minute, the horse-power used in a travelling car is $\frac{11\,WS}{5} \times \frac{1}{33{,}000}$, or

$$HP = \frac{WS}{15{,}000}$$

24. The weight of a loaded automobile is 3250 lbs. What horse-power (HP) is necessary to drive it over a smooth, level road at the rate of 30 miles per hour?

25. An auto-car weighing 4200 lbs. uses 9.8 horse-power in speeding over a level macadamized road. How fast does it go?

26. A motor-car uses 10.4 horse-power while going at the rate of 40 miles per hour over a smooth, level road. What is the weight of the car?

27. An automobile camping-trip along the coast of California shows the following record. The meter read 8852 miles when the party started from Los Angeles.

	Started		Arrived		Meter reading
	Place	Time	Place	Time	
		July			
1	Los Angeles...	19, 3.05 P.M.	San Fernando....	5.25 P.M.	8876
2	Camp........	20, 6.45 A.M.	Santa Barbara....	6.35 P.M.	8970
3	Camp........	21, 7.25 A.M.	Los Olivos.......	6.10 P.M.	9045
4	Camp........	22, 9.30 A.M.	San Luis Obispo..	6.10 P.M.	9105
5	Camp........	23, 8.03 A.M.	Jolon............	7.35 P.M.	9160
6	Camp........	24, 6.05 A.M.	Salinas..........	7.05 P.M.	9246
7	Side trip (Monterey)..	25, 9.20 A.M.	Salinas..........	7.25 P.M.	9306
8	Camp........	26, 8.05 A.M.	Ben Lomond.....	7.40 P.M.	9398
9	Camp........	27, 9.25 A.M.	Redwood Park...	11.45 A.M.	9417
10	Camp........	28, 1.15 P.M.	Divide near Los Gatos.....	6.50 P.M.	9445
11	Camp........	29, 8.50 A.M.	San José.........	1.55 P.M.	9470
			Oakland.........	5.25 P.M.	9515

The expense record of the trip was as follows: July 19, axle, etc., $9.35; 5 gallons gasolene, $1.25; 2 quarts oil, 50 cents. July 22, 5 gallons gasolene, $1.25; 1 gallon oil, 80 cents. July 23, 4 gallons gasolene, $1.00. July 24, 8 gallons gasolene, $2.00, 1 gallon oil, 70 cents. July 26, 8 gallons gasolene, $2.00, 1 gallon oil, 75 cents. July 31, 1 casing (tire), $25.30. At the end of the trip there were 6 gallons of gasolene left.

(a) How long was the trip?

(b) Find the average speed per hour for each day's travel and the average speed per hour for the trip.

(c) Find the total cost of the maintenance of the machine, exclusive of fuel, and the average cost per day.

(d) Find the average cost of gasolene and oil per day and per hundred miles.

19. Formulas concerning Automobiles.

SECTION

Area of Piston: $a = \frac{\pi d^2}{4} = .7854d^2$ 4

Force and Pressure: $\left.\begin{aligned} F &= Pa \\ F &= \frac{P\pi d^2}{4} \end{aligned}\right\}$ 5

Foot-pounds of Energy: $\left.\begin{aligned} E &= \frac{Pla}{12} \\ E &= \frac{Pl\pi d^2}{48} \end{aligned}\right\}$ 5

Energy per Minute per Cylinder: $E = \frac{Plan}{24}$ . . . 6

Energy per Minute: $E = \frac{Planc}{24}$ 6

Horse-Power of Engine: $HP = \frac{E}{33{,}000} = \frac{Planc}{24 \times 33{,}000}$ . . 8

$$\text{or } HP = \frac{Pl\pi d^2 nc}{96 \times 33{,}000}$$

$$\text{also } HP = .224(d + l)dc \quad \text{(In 1915)}$$

$$HP = \tfrac{2}{5}d^2c \quad \text{(In 1916)}$$

Gears in Mesh: $\frac{t}{t'} = \frac{r'}{r}$ or $tr = t'r'$ 9

Revolutions of Pinion: no. rev. $= \frac{rt_1t_2}{t_1't_2'}$ 14

Final Gear Ratio $= \frac{\text{rev. rear wheel}}{\text{rev. fly-wheel}}$ 15

Distance Travelled: $d = nrcm$ 15

Foot-Pounds of Energy to Keep Car Running: $E = \frac{11\,WS}{5}$ . . . 18

Horse-Power of Moving Car: $HP = \frac{WS}{15{,}000}$ . . . 18