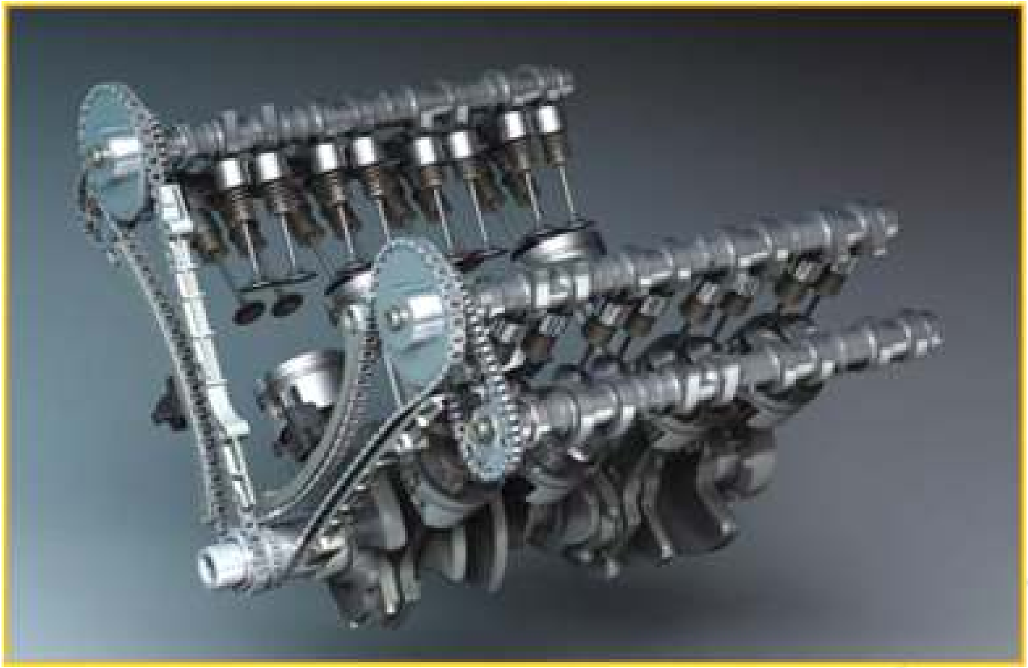
Internal Combustion Engine Theory



Objectives

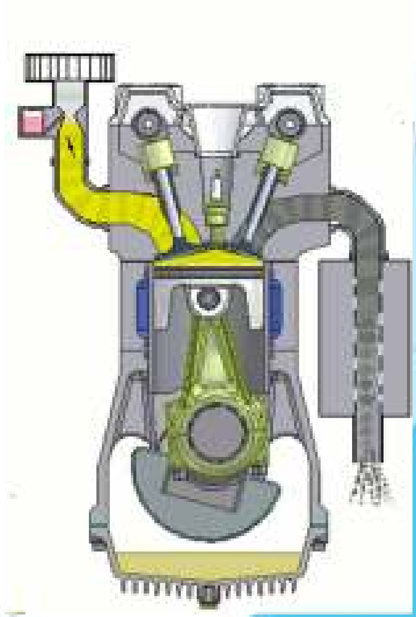
- Understand the theory of operation for a four stroke cycle internal combustion engine.
- Identify the major components of a reciprocating piston engine.
- Understand engine classification and construction.
- Understand the operation of a four stroke cycle engine.

Types of Engines

- External Combustion Engine
- Heat engine
- Fluid is heated by combustion externally from the engine
- Heated fluid expands in the engine and acts on the mechanism of the engine that produces motion

Internal combustion engine

- Combustion of fuel and air occurs within the engine.
- It occurs in enclosed space in the engine known as combustion chamber.



Reciprocating Engine Classification

- Number of cylinders
- Cylinder layout i.e. V type, inline, horizontally opposed
- Location of the valves
- Location of the camshaft

Cylinder Configurations

- In-line design
- V design
- W design
- Horizontally opposed design

ENGINE CLASSIFICATION AND CONSTRUCTION

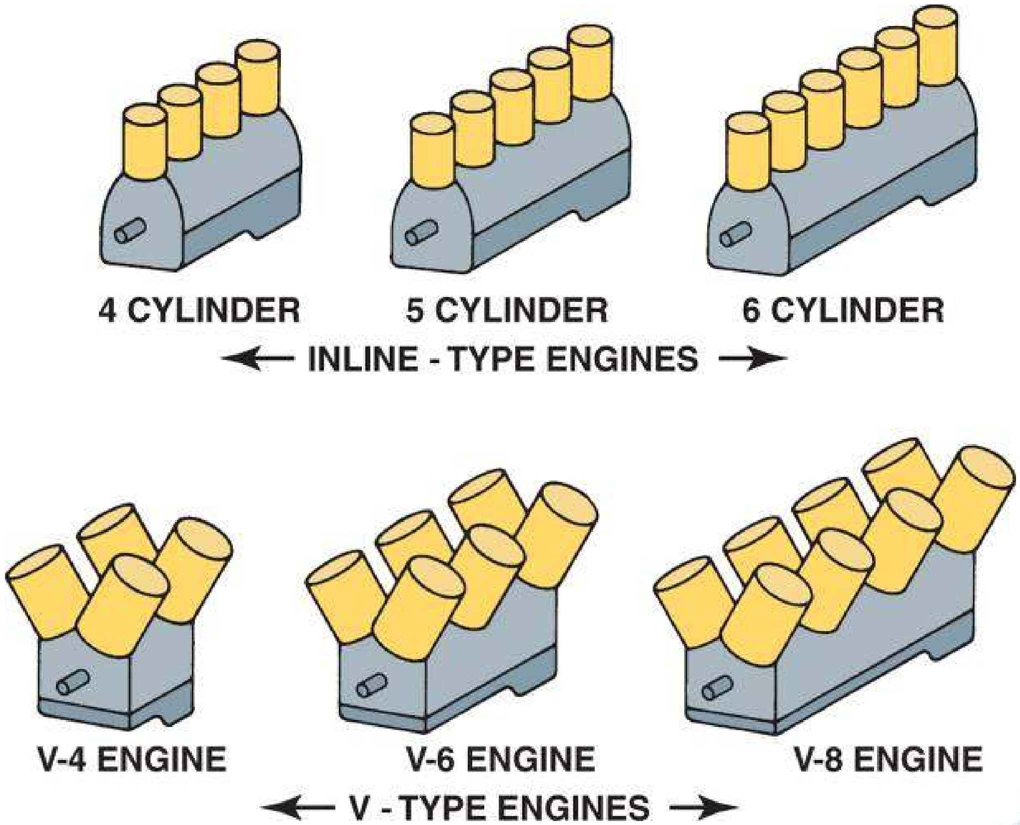


FIGURE 10-7 Automotive engine cylinder arrangements.

Horizontally Opposed

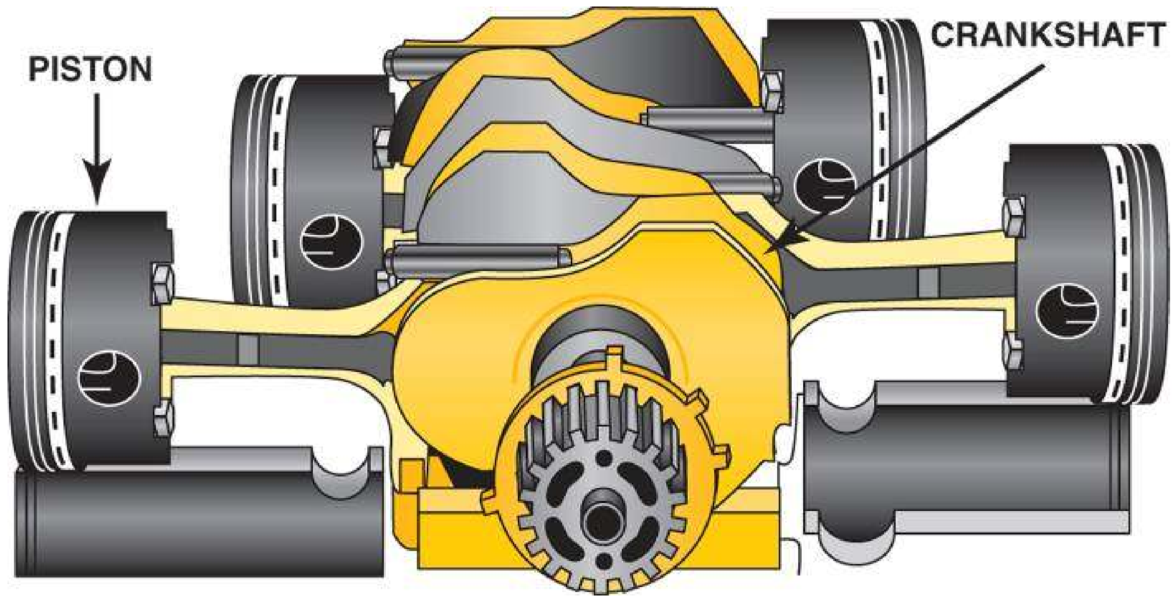


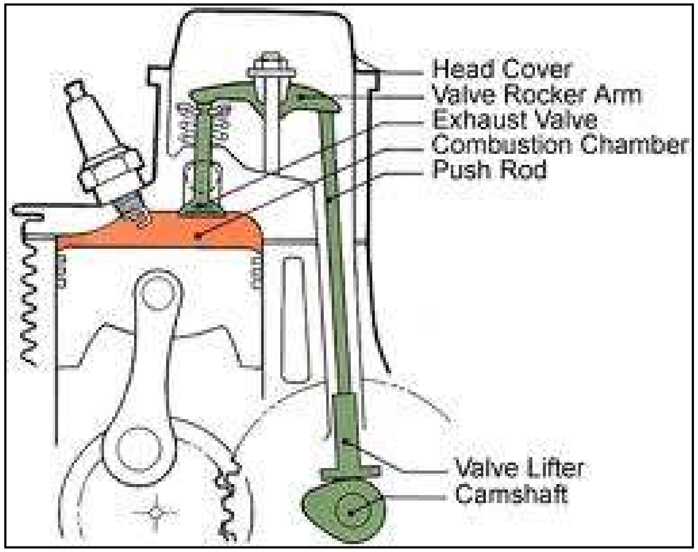
FIGURE 10-8 A horizontally opposed engine design helps to lower the vehicle's center of gravity.

W Design

- W12 engine is two V6 engines in a W configuration
- W16 is two V8s

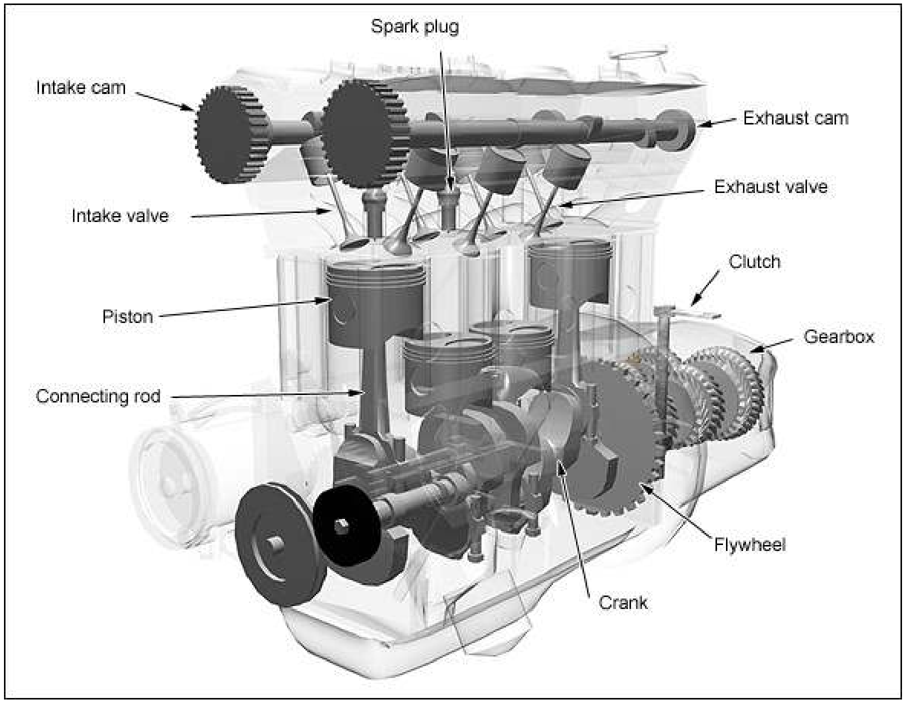
W Design Block vs. V Design

Overhead Valve (OHV) Design



- Valves are located in the cylinder head
- Camshaft is located in the engine block
- Also known as a pushrod engine

Overhead Cam Design (OHC)



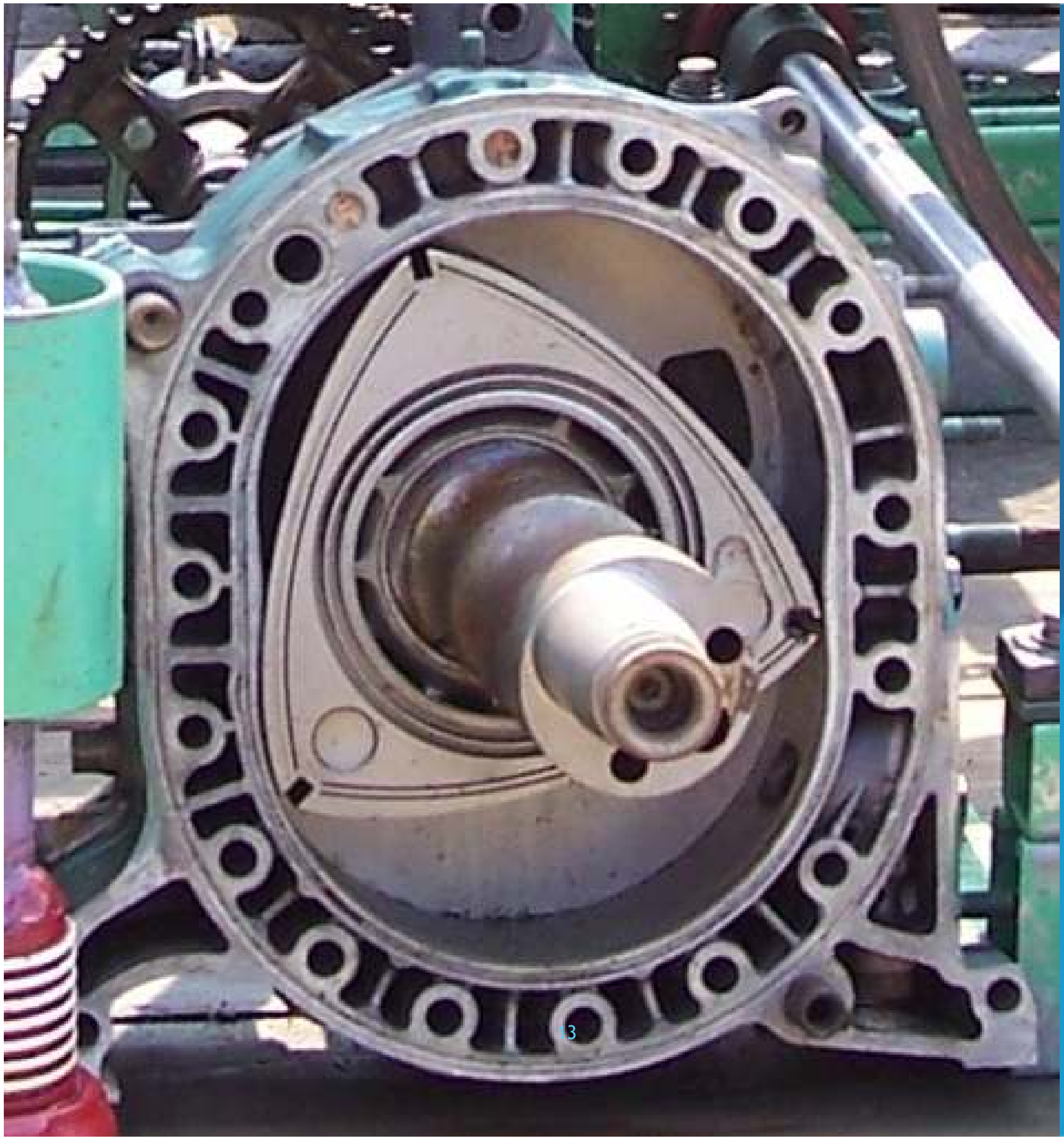
- Valves and camshaft located in cylinder head
- OHC single overhead cam
- DOHC dual overhead cam
- Does not require pushrods

Rotary Engine

No Pistons

Revs high

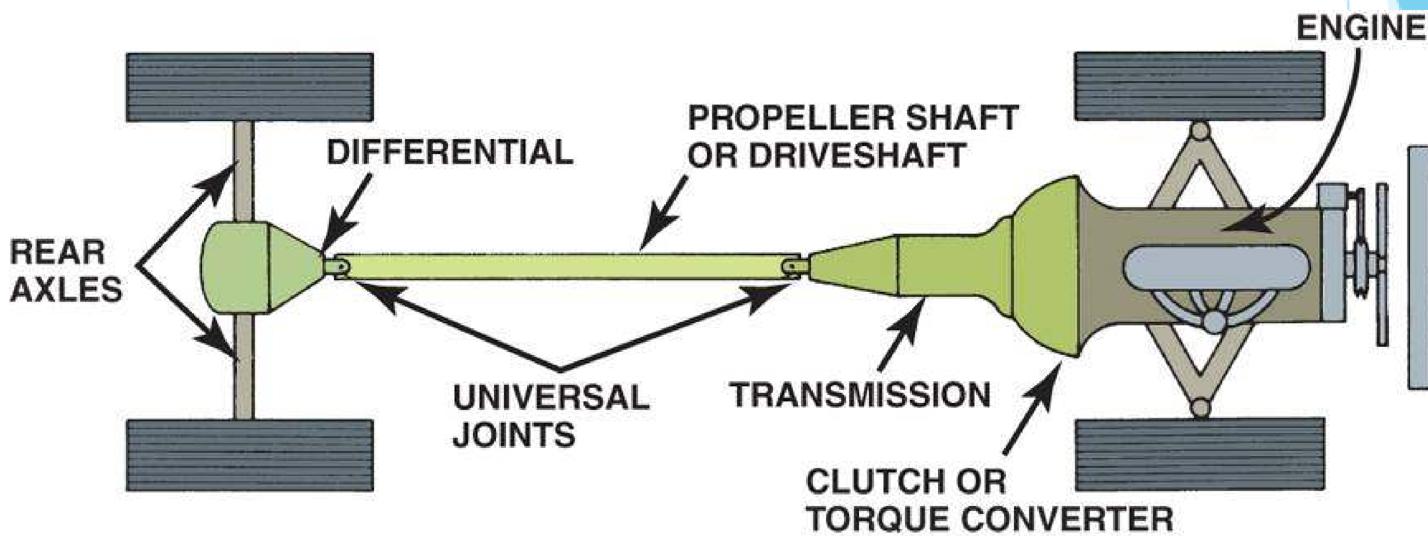
Low Torque



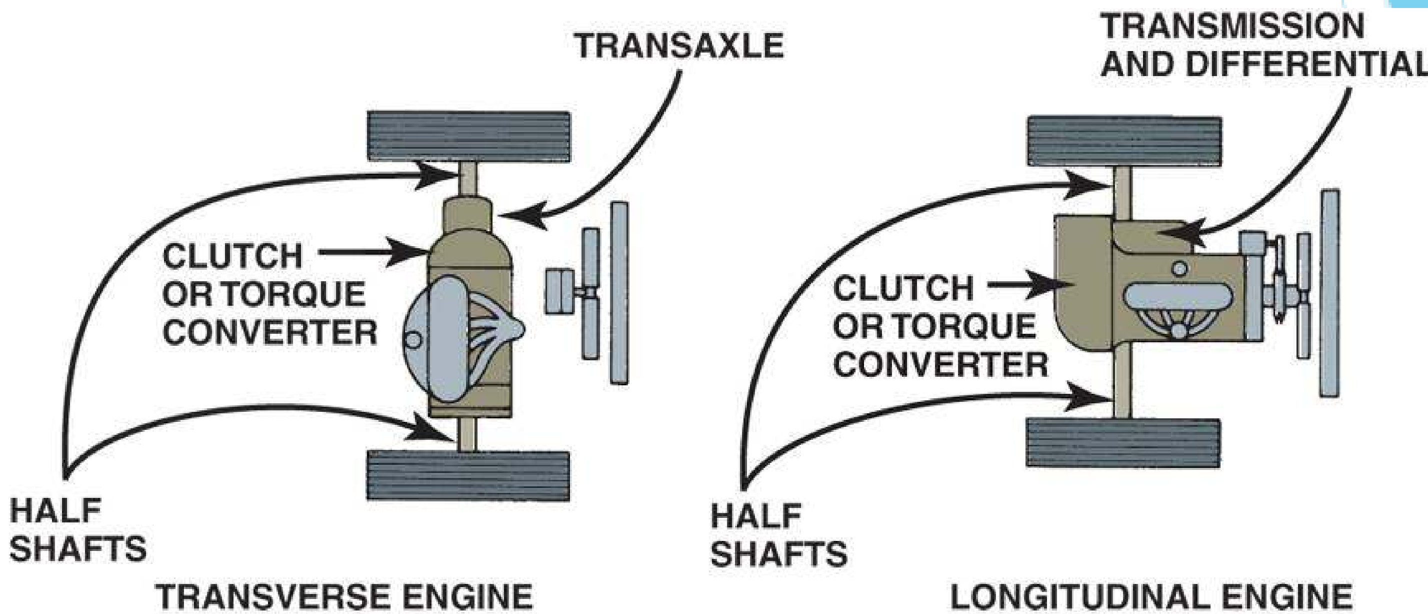
Engine Mounting

- Longitudinal
- Transverse mounted
- Front engine
- Rear engine
- Mid engine

Longitudinally mounted engine / Rear Wheel Drive

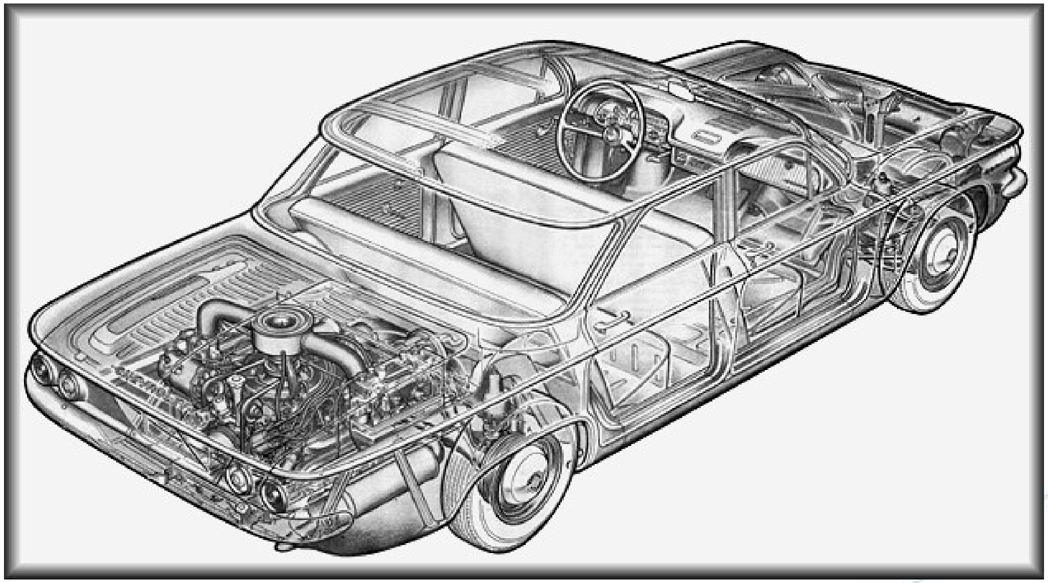


Front Wheel Drive Vehicle



Rear Engine

- Engine mounts behind rear axle



Mid-engine

- Engine mounts in front of rear axle

Engine size

- Measure of its displacement
- Displacement is the volume of air displaced by all of the cylinders measured in cubic inches (CID), cubic centimeters (CC), or cubic liters
- Volume of one cylinder times the number of cylinders.
- Volume is determined by the diameter of a cylinder (bore) and the measured distance the piston travels from top of the cylinder to the bottom (stroke).

ENGINE MEASUREMENT

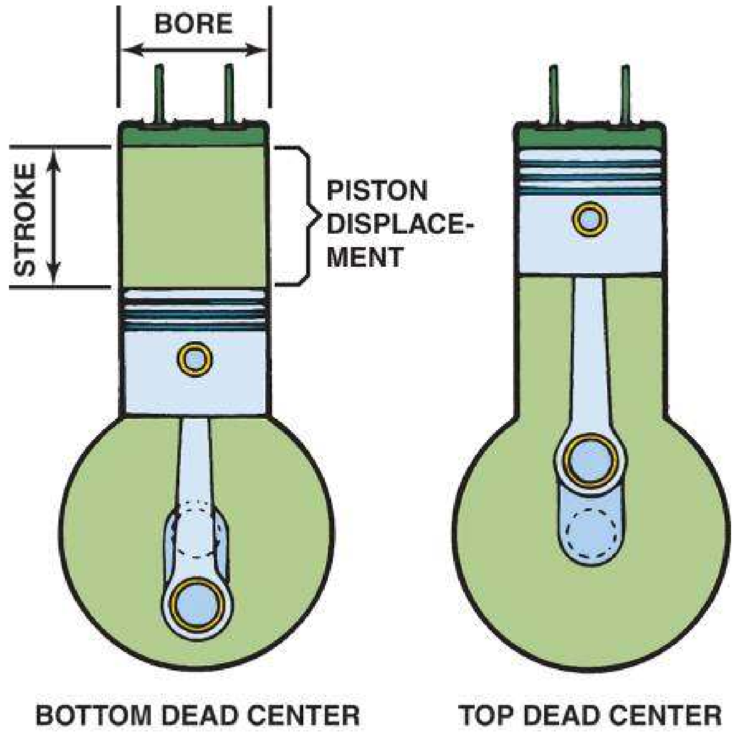


FIGURE 10-16 The bore and stroke of pistons are used to calculate an engine's displacement.

Calculating Displacement

- .785 X Bore X Bore X Stroke X Number of Cylinders
- .785 is a constant (π = 3.14159 / 4 = .78539)
- 350 CID Chevrolet engine has a 4 inch bore, a 3.48 inch stroke and 8 cylinders
- .785 x 4 x 4 x 3.48 x 8 = 349.7 CID

Society of Automotive Engineers (SAE)

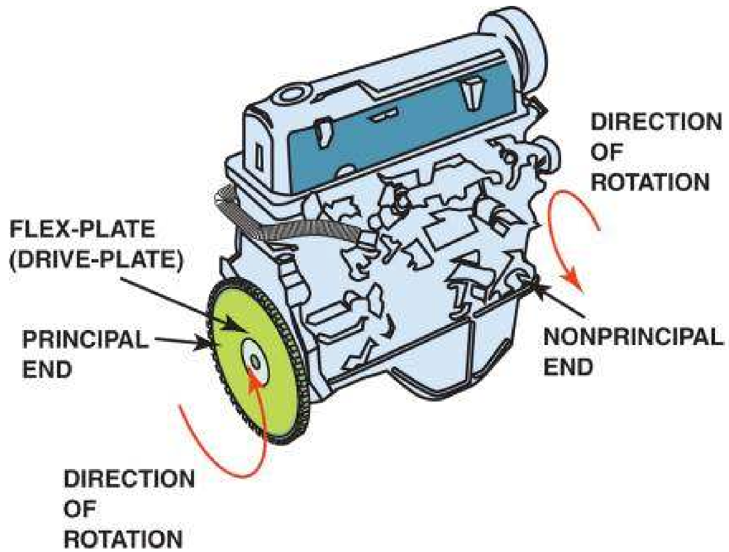


FIGURE 10-15 Inline 4-cylinder engine showing principal and nonprincipal ends. Normal direction of rotation is clockwise (CW) as viewed from the front or accessory belt (nonprincipal) end.

Four Stroke Cycle Engine

- Requires four strokes of the piston to complete a cycle and produce power.
- A cycle is the complete series of 4 strokes.
- Continually repeats the cycle.

Pulsed Combustion Engines

- Air and fuel are delivered to the combustion chamber in pulses at a specific time in the engine's cycle.
- The air and fuel are compressed in the combustion chamber
- Compression raises molecular activity of the molecules, which increases the temperature and pressure of the mixture

Number of Cylinders

- The more cylinders, the more power the engine can produce.
- Because more power pulses produced in one 720-degree cycle.
- This produces a smoother running engine.

Engine Pulses and Smoothness

- An engine's power delivery occurs in jerks every time a combustion takes place
- 1 cylinder delivers power every 720° of rotation
- 4 cylinders deliver power every 180°
- 6 cylinders deliver power every 120°
- Eight cylinders deliver power every 90°
- More cylinders = more power strokes = smoothness

Four Stroke Cycle

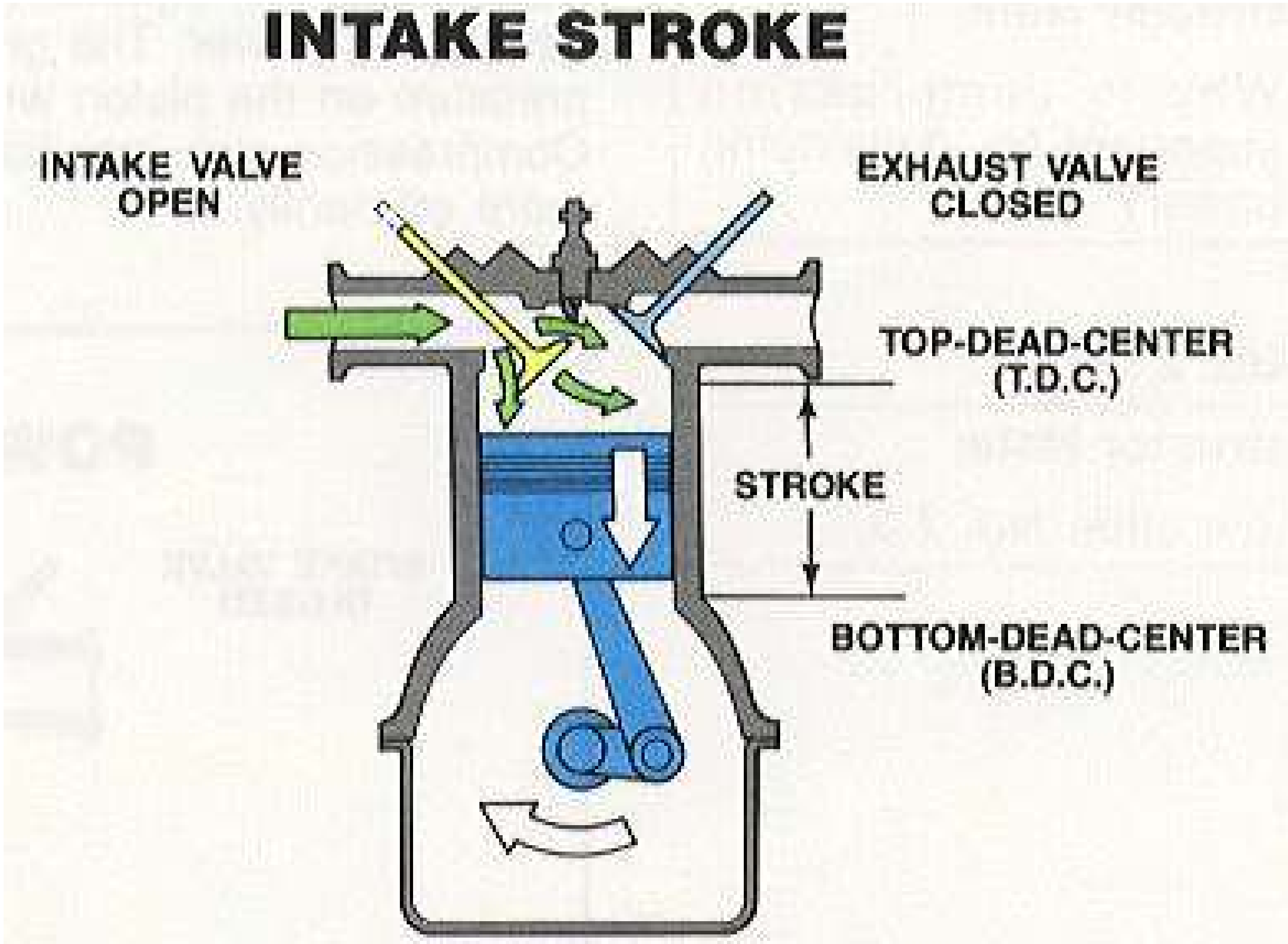
- An air and fuel mixture is drawn into the engine's combustion chamber where it is compressed, increasing it's temperature and pressure.
- This volatile mixture is ignited and it combustion occurs.
- The explosion causes the compressed high-pressure gasses to expand rapidly.
- This expansion applies force to the piston moving it downward and mechanical energy.

4 Stroke Cycle Engine / 720 Degree Cycle

- Complete 4 stroke cycle:
  - Intake stroke (180 degrees) Draws in air and fuel
  - Compression Stoke (180 degrees) Compresses mixture to increase volatility
  - Power Stroke (180 degrees) Only creates power on this stroke
  - Exhaust Stroke (180 degrees)
- Requires two rotations (720 degrees) to complete the cycle.
- 1 cylinder engine produces power every 720 degrees or once every two revolutions.

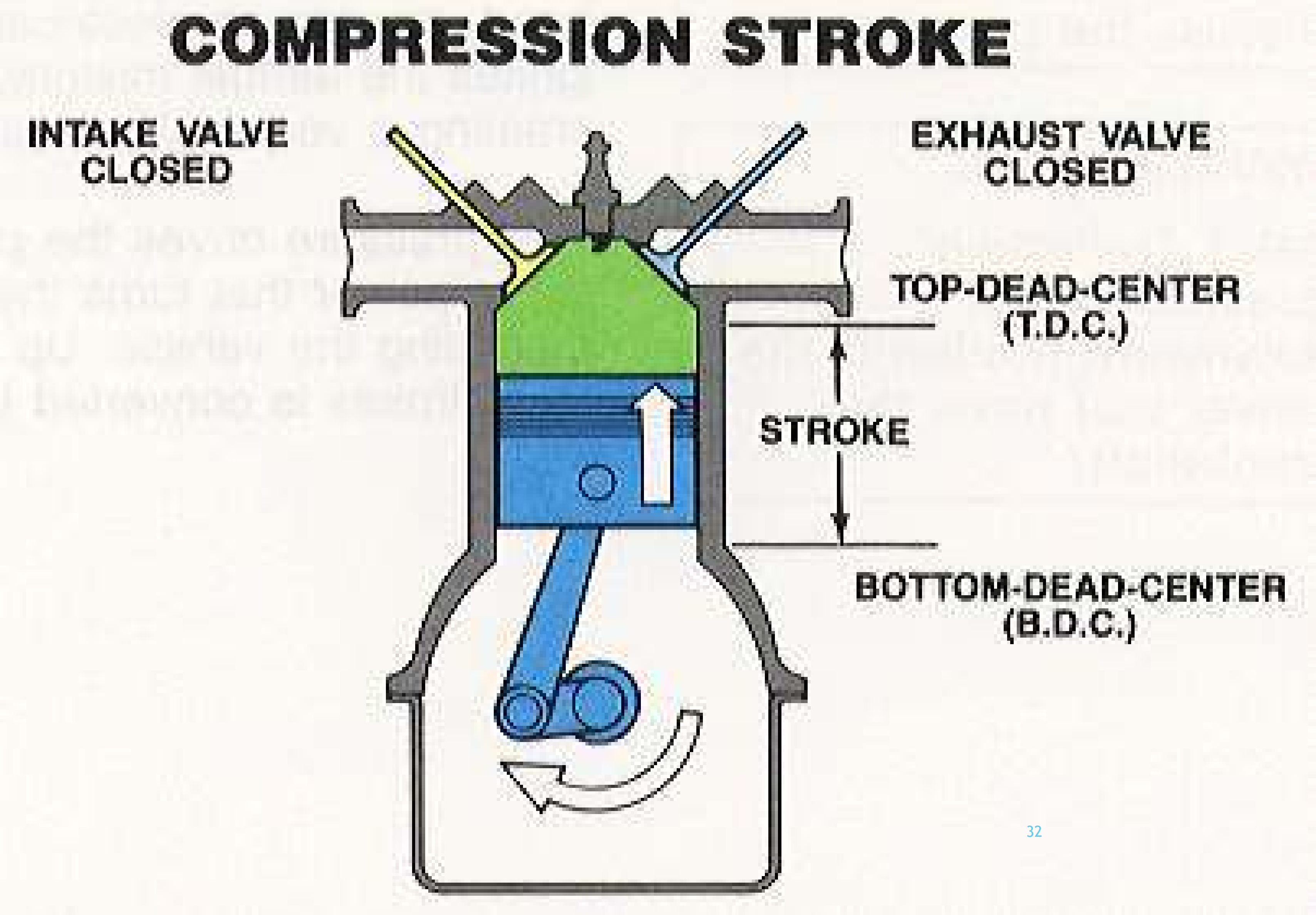
Intake Stroke

- Begins with the piston at the top of the cylinder bore
  - Top Dead Center (TDC)
- The intake valve is open at the beginning of the stroke; the exhaust valve is closed
- Stroke ends with the piston at the bottom of the cylinder bore
  - Bottom Dead Center (BDC)
- As the crankshaft pulls the **piston down the cylinder on the intake stroke** a mixture of air and fuel is drawn into the cylinder
- The crankshaft rotates 180 degrees from TDC to BDC on the intake stroke


INTAKE STROKE
INTAKE VALVE OPEN
EXHAUST VALVE CLOSED
TOP-DEAD-CENTER (T.D.C.)
STROKE
BOTTOM-DEAD-CENTER (B.D.C.)

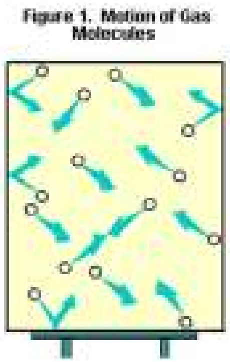
Compression Stroke

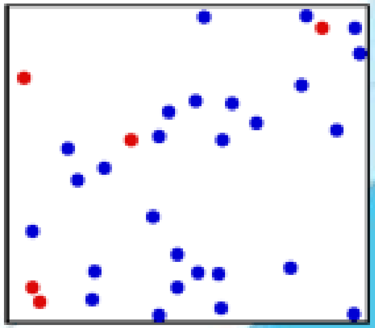
- Begins at as the piston passes BDC after the end of intake stroke
- Both intake and exhaust valves are closed
- As the **piston move up the cylinder on the compression stroke** it squishes the air fuel mixture
- Near TDC at the end of the compression stroke the ignition system fires the spark plug, which ignites the compressed air/fuel mixture causing it to combust.
- The crankshaft moves 180 degrees from BDC to TDC on the compression stroke


COMPRESSION STROKE
INTAKE VALVE
CLOSED
EXHAUST VALVE
CLOSED
TOP-DEAD-CENTER
(T.D.C.)
STROKE
BOTTOM-DEAD-CENTER
(B.D.C.)

Molecular Velocity

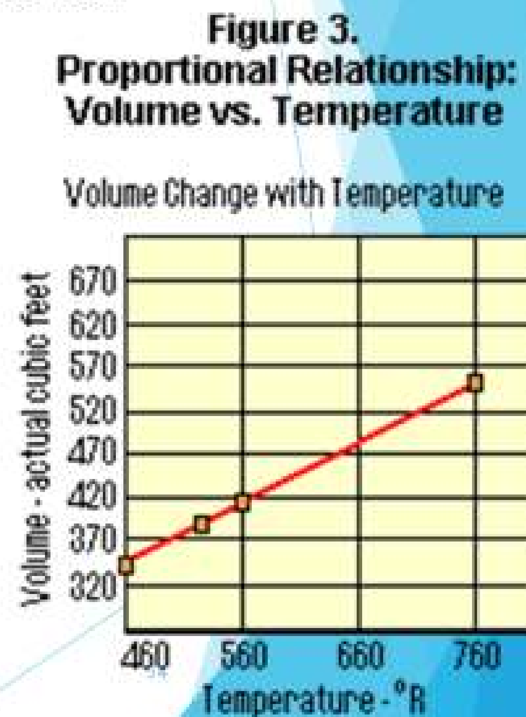
- Gases are composed of molecules, which are moving rapidly within the volume they occupy
- Molecules collide elastically with each other and the container, creating pressure.
- The velocities of the molecules depend on the temperature.





Temperature and Pressure

- Gay-Lussac's Law
  - Temperature and pressure of a gas are directly proportional.
- **As temperature increases, pressure increases**

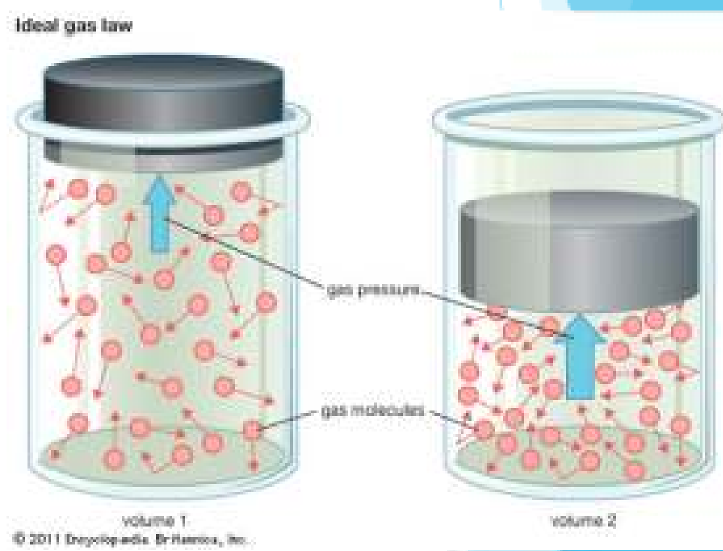


Volume Change and Temperature

- Charles’s Law:
  - The volume of a given mass of a gas increases or decreases by the same factor as its temperature
    - A Hot Air Balloon is a classic example of Charles's law.
    - On ignition of the fuel, the air inside the balloon heats up and expands.
    - As the temperature of the air increases, the volume of the air also increases and consequently, the density decreases.

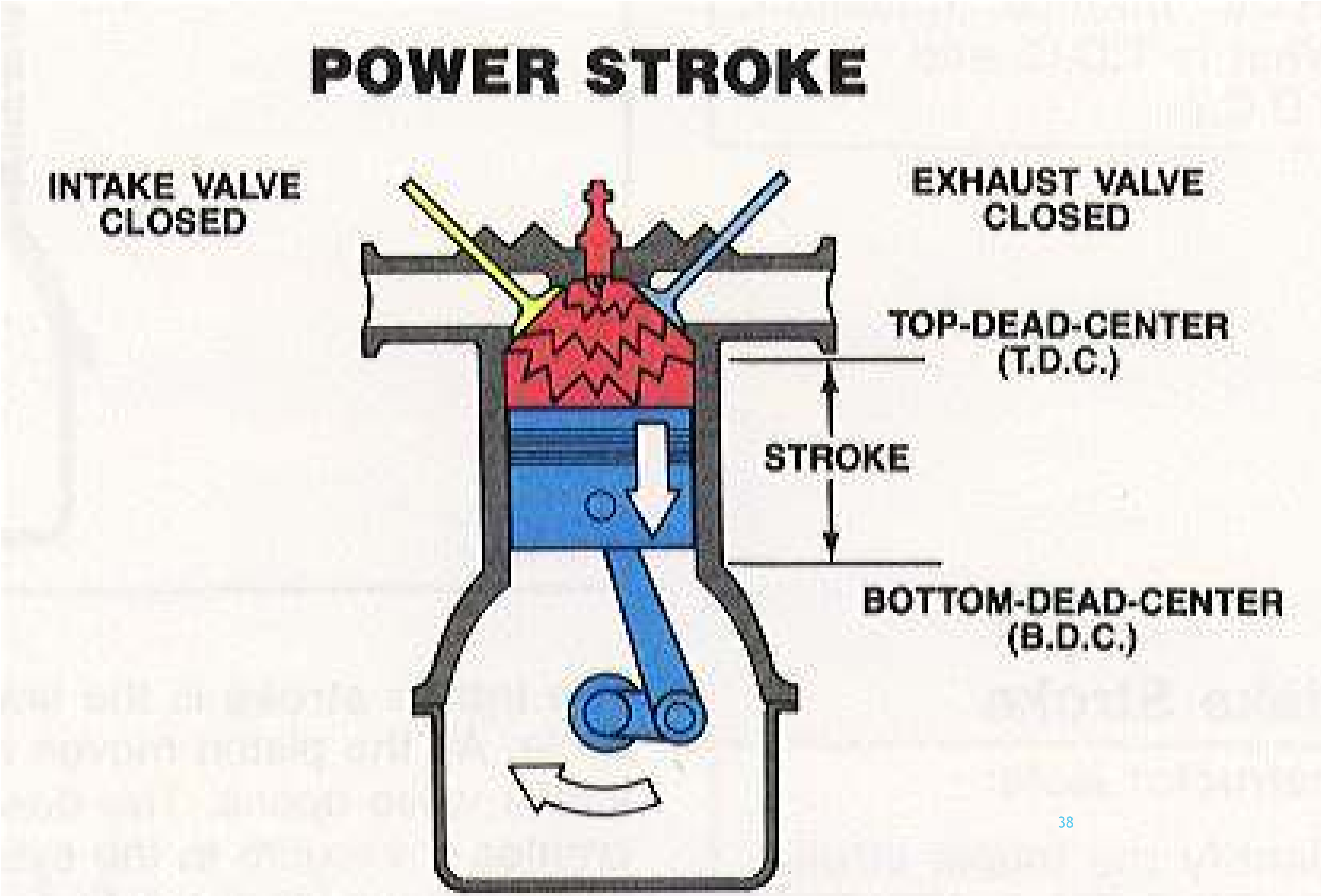
Pressure and Volume

- Boyle's law:
  - Pressure and volume of a gas are inversely proportional
- As volume decreases pressure increases
- When compressed into a smaller volume the molecular collisions increase, raising the gas's temperature and pressure



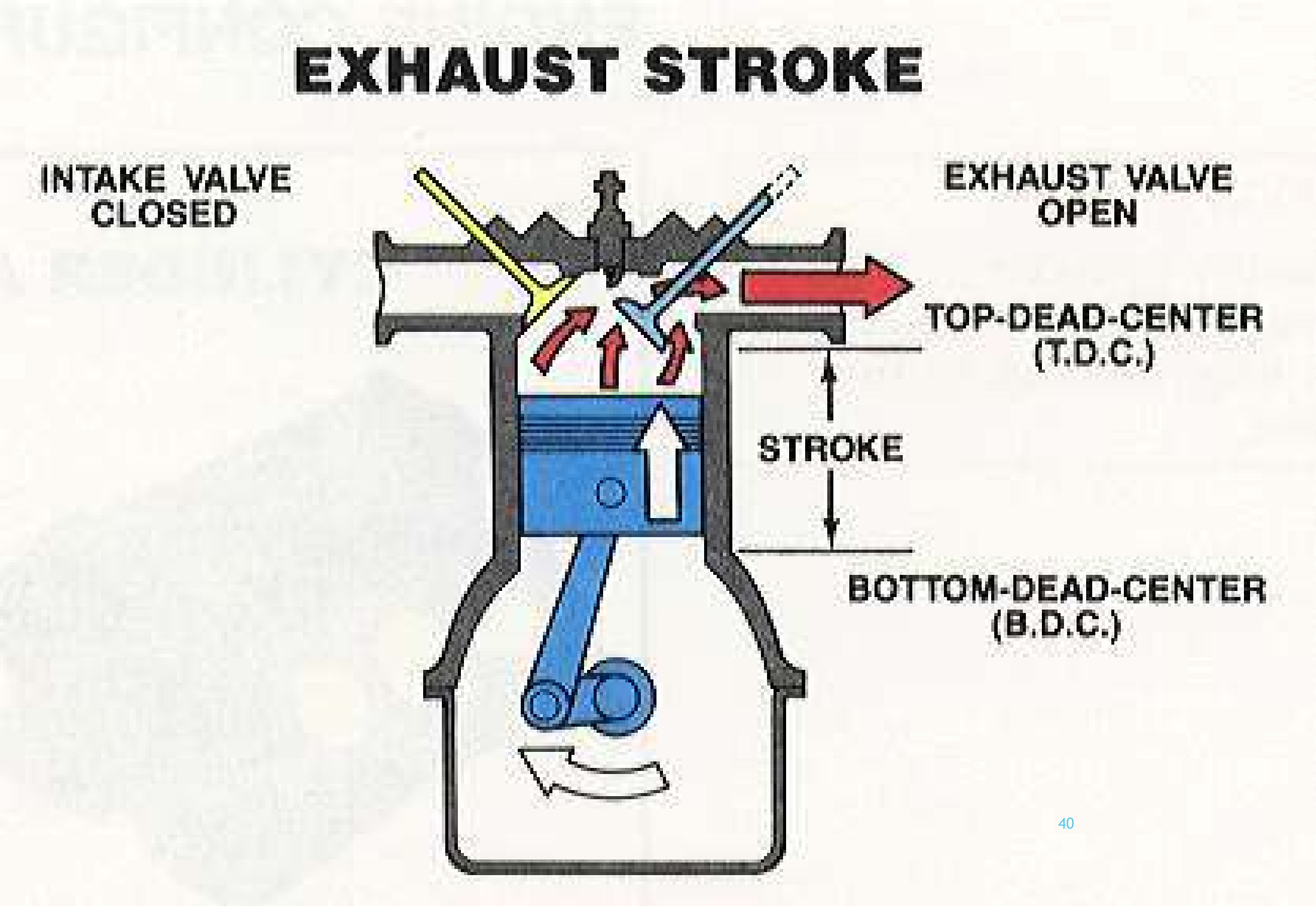
Power Stroke

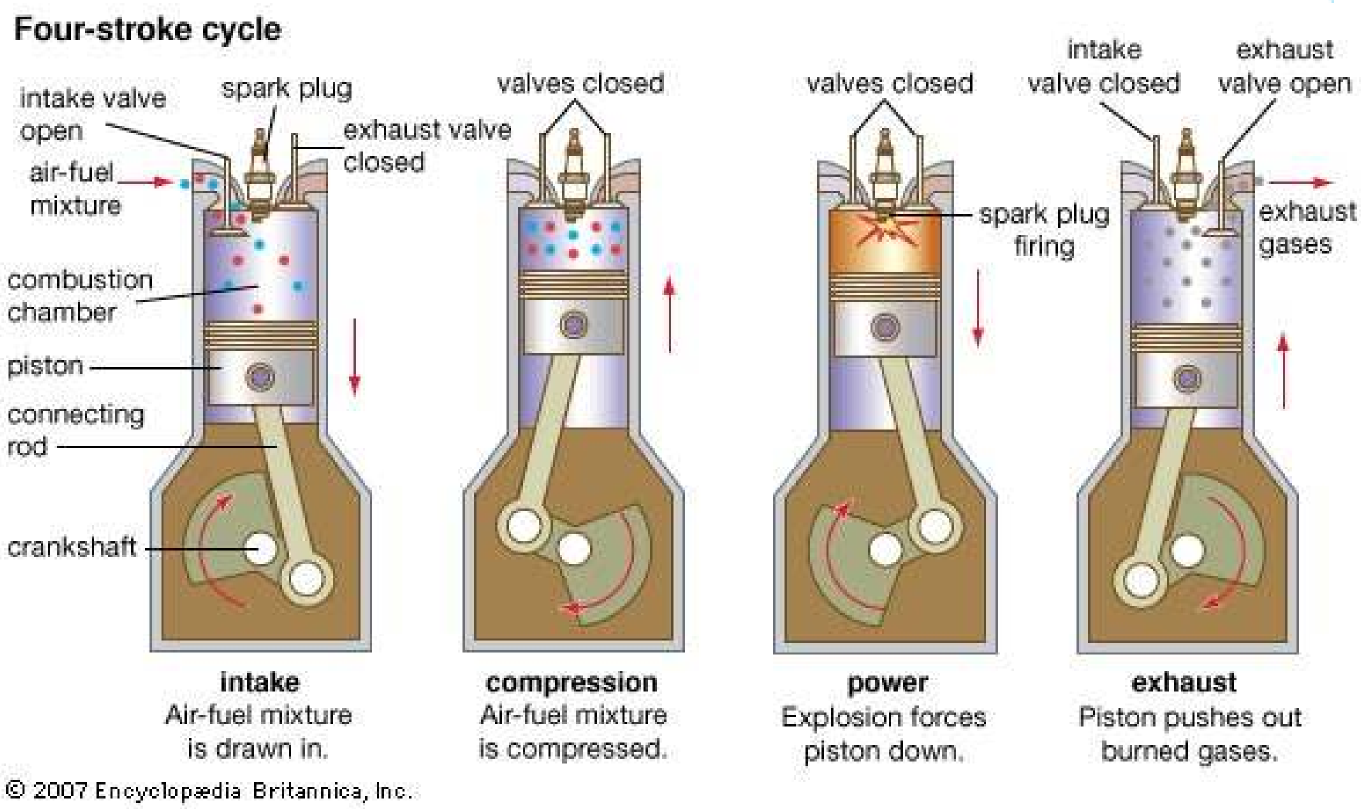
- Begins at TDC after the compression stroke
- Both the intake and exhaust valve are closed
- The combustion of the air/fuel mixture drives the piston downward with a powerful force
- This downward force rotates the crankshaft
- When the piston nears BDC the exhaust valve starts to open
- The crankshaft moves 180 degrees from TDC to BDC on the power stroke


POWER STROKE
INTAKE VALVE CLOSED
EXHAUST VALVE CLOSED
TOP-DEAD-CENTER (T.D.C.)
STROKE
BOTTOM-DEAD-CENTER (B.D.C.)

Exhaust Stroke

- Begins at BDC following the power stroke
- The force created on the power stroke causes the crankshaft to push the piston upward in the cylinder
- The exhaust valve opens
- The upward movement of the piston pushes the burned gasses out of the cylinder
- The crankshaft rotates 180 degrees from BDC to TDC on the exhaust stroke
- The cycle then repeats beginning with the intake stroke


EXHAUST STROKE
INTAKE VALVE
CLOSED
EXHAUST VALVE
OPEN
TOP-DEAD-CENTER
(T.D.C.)
STROKE
BOTTOM-DEAD-CENTER
(B.D.C.)


Four-stroke cycle
intake valve open
spark plug
exhaust valve closed
air-fuel mixture
combustion chamber
piston
connecting rod
crankshaft
valves closed
valves closed
spark plug firing
intake valve closed
exhaust valve open
exhaust gases
intake
Air-fuel mixture is drawn in.
compression
Air-fuel mixture is compressed.
power
Explosion forces piston down.
exhaust
Piston pushes out burned gases.
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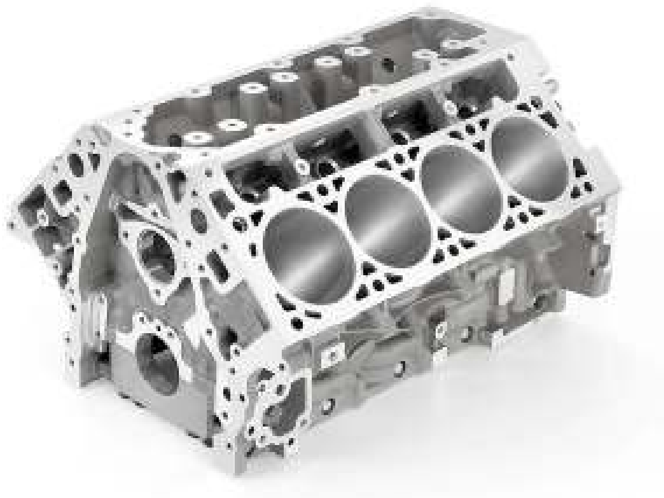
Review

- What are the four strokes of a four-stroke cycle engine?
- Intake, compression, power and exhaust
- How many revolutions does the crankshaft make to complete one cycle?
- Two revolutions

Engine Components

- Cylinder Block
- Crankshaft
- Pistons and Connecting Rods
- Cylinder Heads
- Camshaft and valve train

The Engine Block

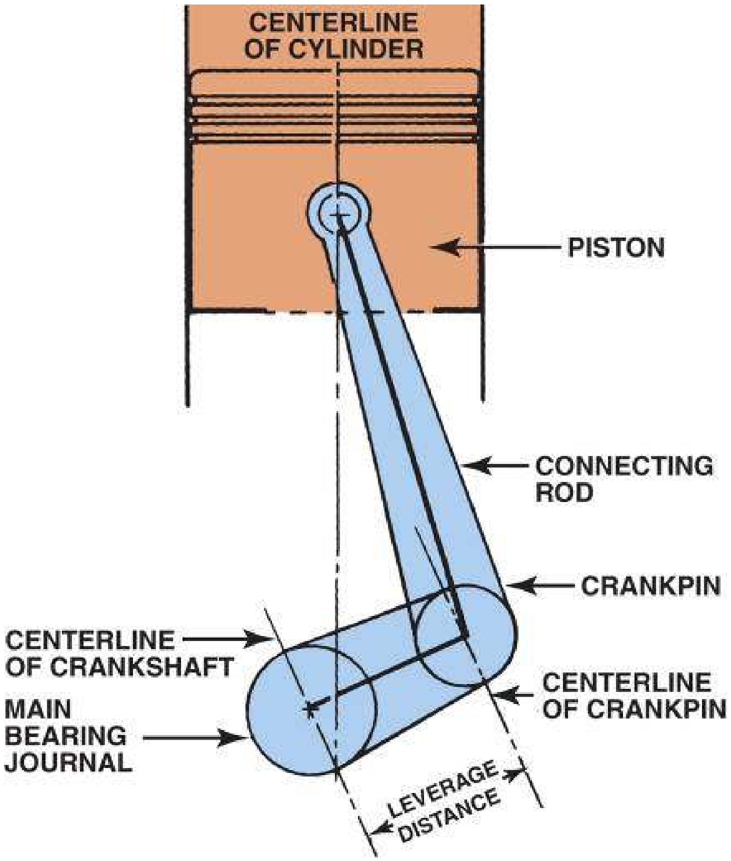


- Supporting structure for the entire engine
- Monoblock design
- All engine parts are mounted to the block
- Supports the crankshaft and camshaft; and holds all parts in alignment
- Cylinder are called bores
- Cast iron or aluminum alloy

Crankshaft

Crankshaft Purpose and Function

- Largest moving part of an engine
- Receives the power impulses from cylinders
- Changes reciprocating motion into rotary motion
- Transmits torque to the transmission



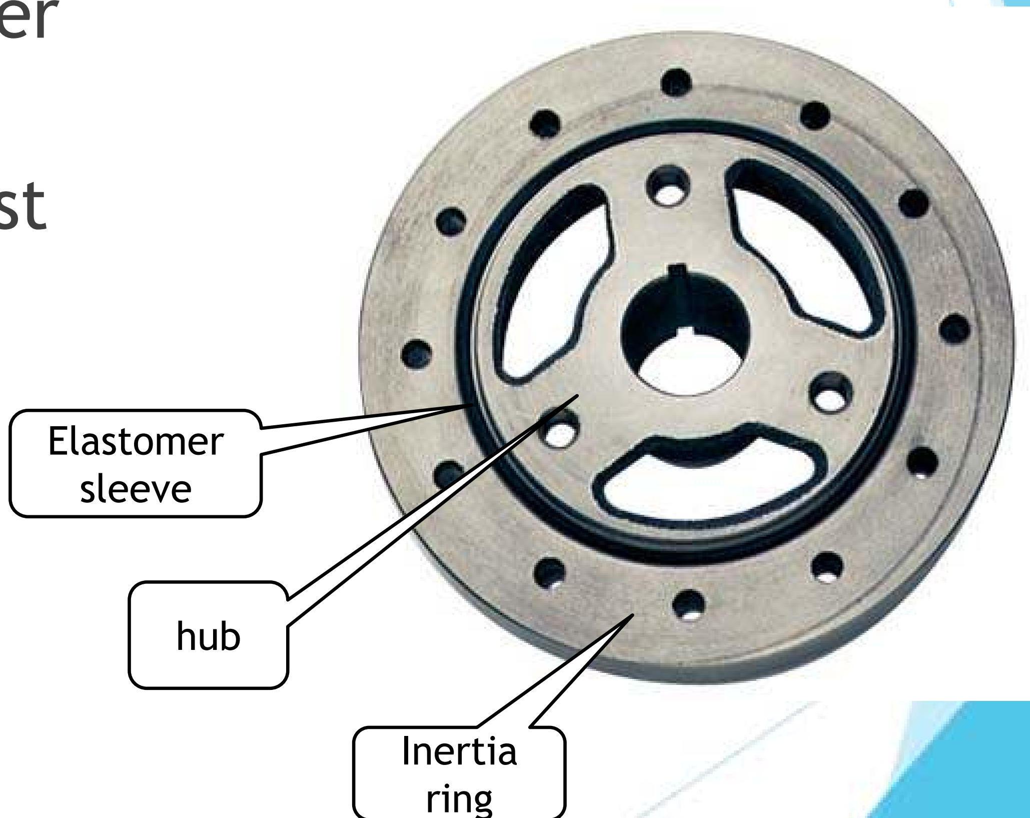
Stroke

The distance from the crankpin centerline to the centerline of the crankshaft determines the stroke, which is the leverage available to turn the crankshaft.

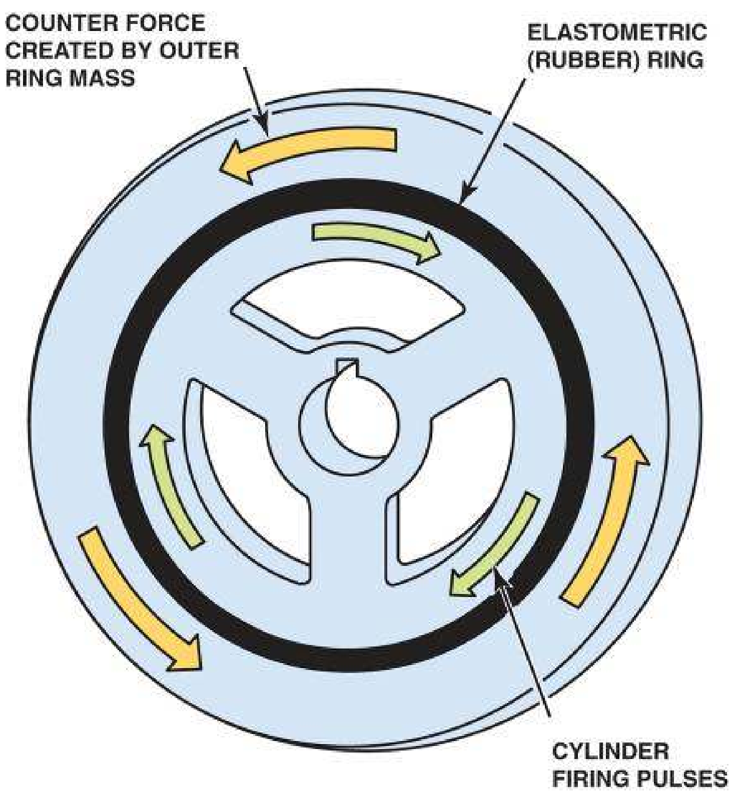
The stroke is twice this distance.

Torsional Vibration Dampner

- Harmonic Balancer
- Inertia ring mounted on a cast iron hub with an elastomer sleeve



COUNTERWEIGHTS



The hub of the harmonic balancer is attached to the front of the crankshaft.

The elastomer (rubber) between the inertia ring and the center hub allows the absorption of crankshaft firing impulses.

PISTONS, RINGS & CONNECTING RODS

Piston

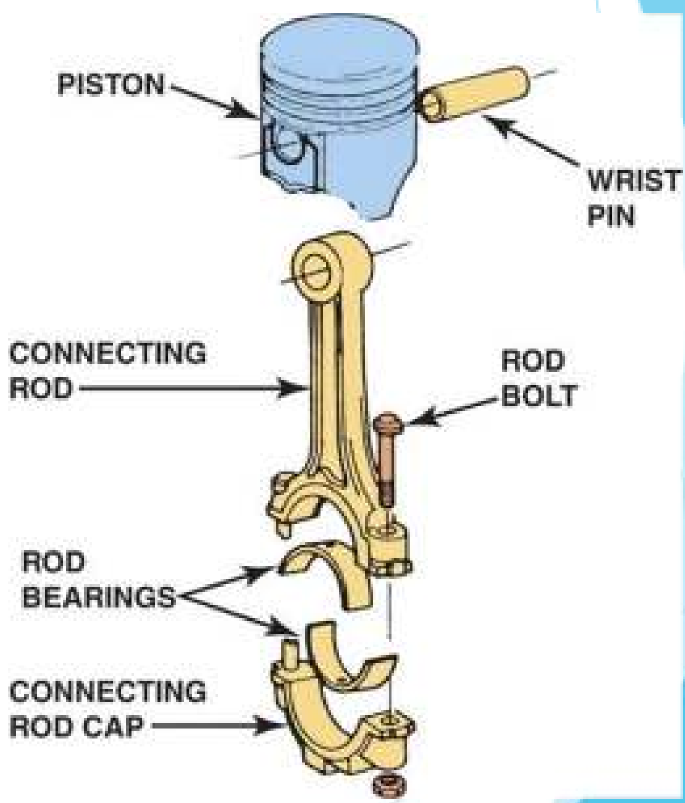
- Forms the bottom combustion chamber
- Receives the load from the combustion
- Transfers load to the crankshaft via the connecting rod
- Acts as a heat conductor

Ring Functions

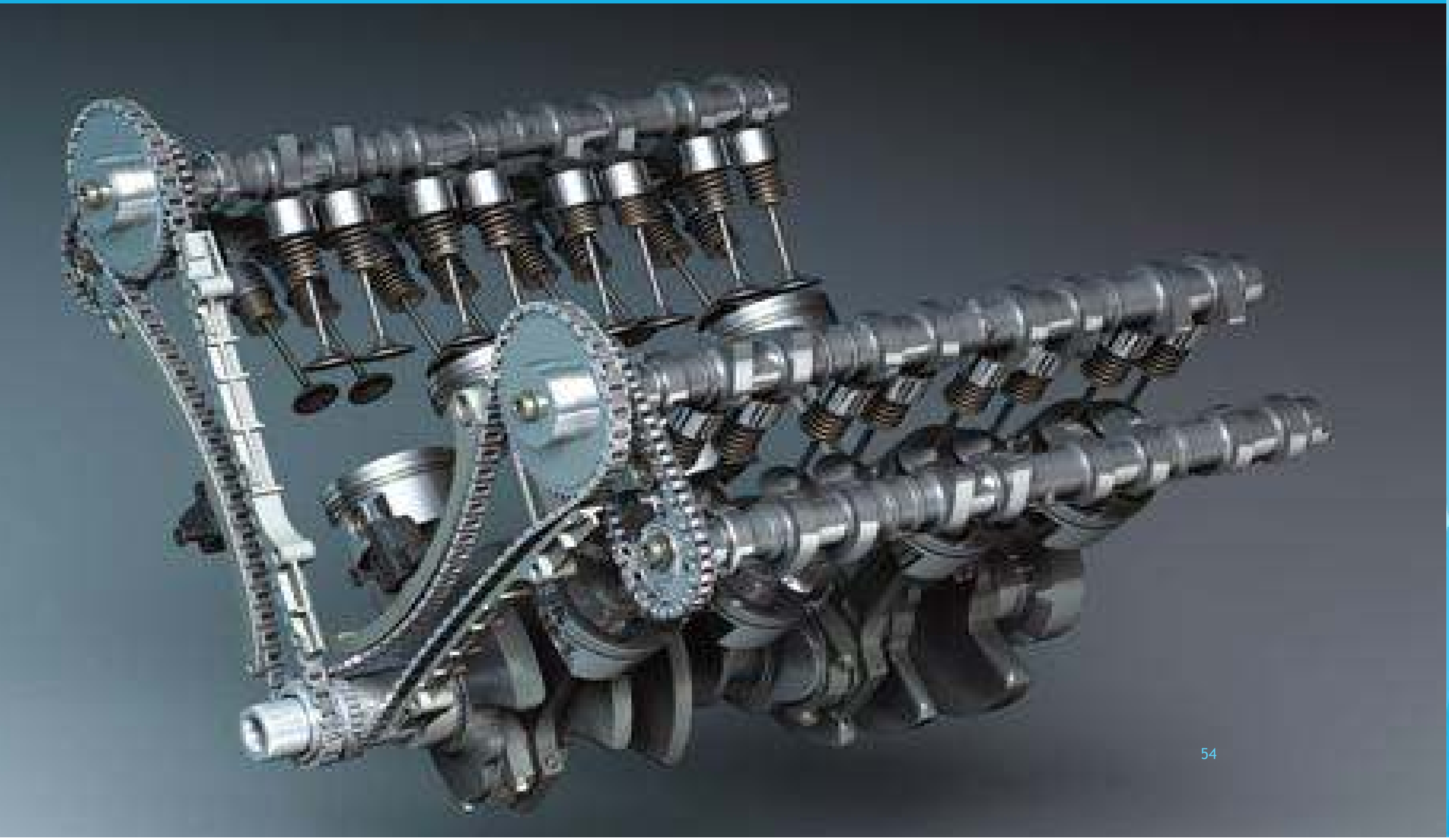
- Form a sliding seal for combustion chamber
- Prevent combustion gases from entering the crankcase
- Keep the engine oil out of the combustion chamber
- Act as a heat sink for the piston to transfer its heat to the cylinder wall
- Classifications
  - Compression rings: keep gasses in combustion chamber
  - Oil rings: keep oil out of combustion chamber

Connecting Rods

- Transfers the force form combustion to the crankshaft
- **Highest stressed part of the engine**
  - Combustion tries to compress it
  - Piston inertia tries to pull it apart

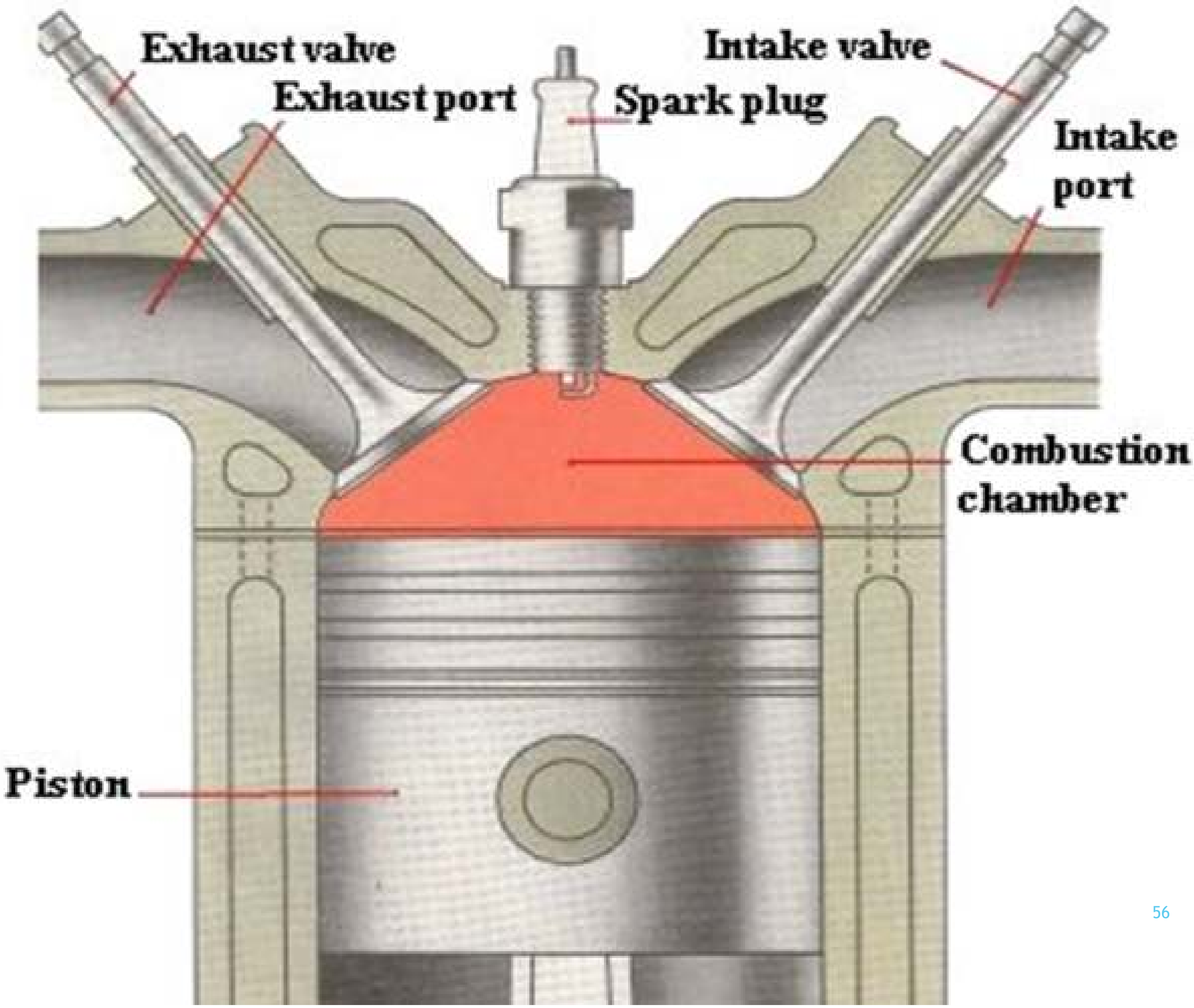


Cylinder Heads



Cylinder Heads

- Contain valves and valve train components
- Cast iron or aluminum
- Direct the flow of intake and exhaust gasses
- Forms top of the Combustion chamber
- Seals to the cylinder block with at cylinder head gasket


Exhaust valve
Exhaust port
Spark plug
Intake valve
Intake port
Combustion chamber
Piston

Combustion Chamber

- The area located directly above the piston where the combustion occurs
- Contains the spark plug and the valves
- Volume of the combustion chamber and piston design determines compression ratio
  - Measured in cubic centimeters (cc)

Camshafts and Valve Timing

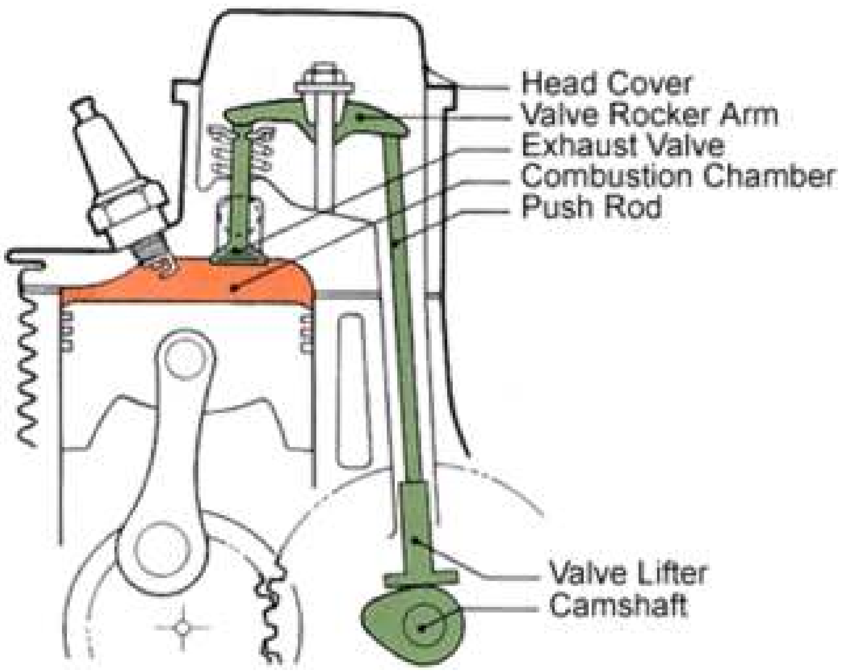
Camshaft

- A shaft running the length of the cylinder bank with a number of oblong *lobes* protruding from it
- One for each intake and exhaust valve
- Major function is to open the valves
- **It changes rotary motion into linear motion**
- Driven by the crankshaft
- **Turns at one-half the speed of the crankshaft**
- It is a major factor in determining engine performance
  - If the cylinder head is the heart of the engine, the camshaft is the brain

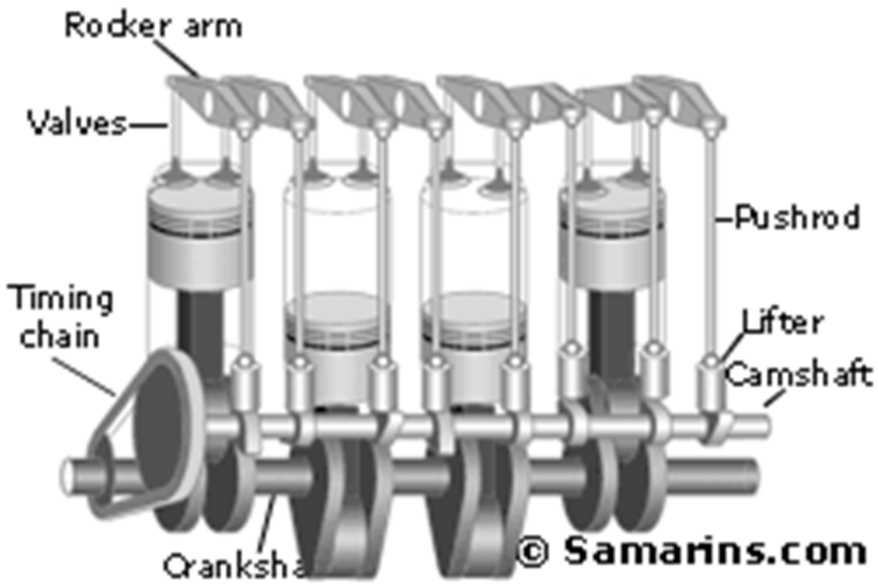
Overhead Valve Design (OHV)

- Cam located in engine block
- Supported in the block by camshaft bearings
- Chain or gear driven
- Uses lifters, pushrods and rocker arms

Overhead Valve Design



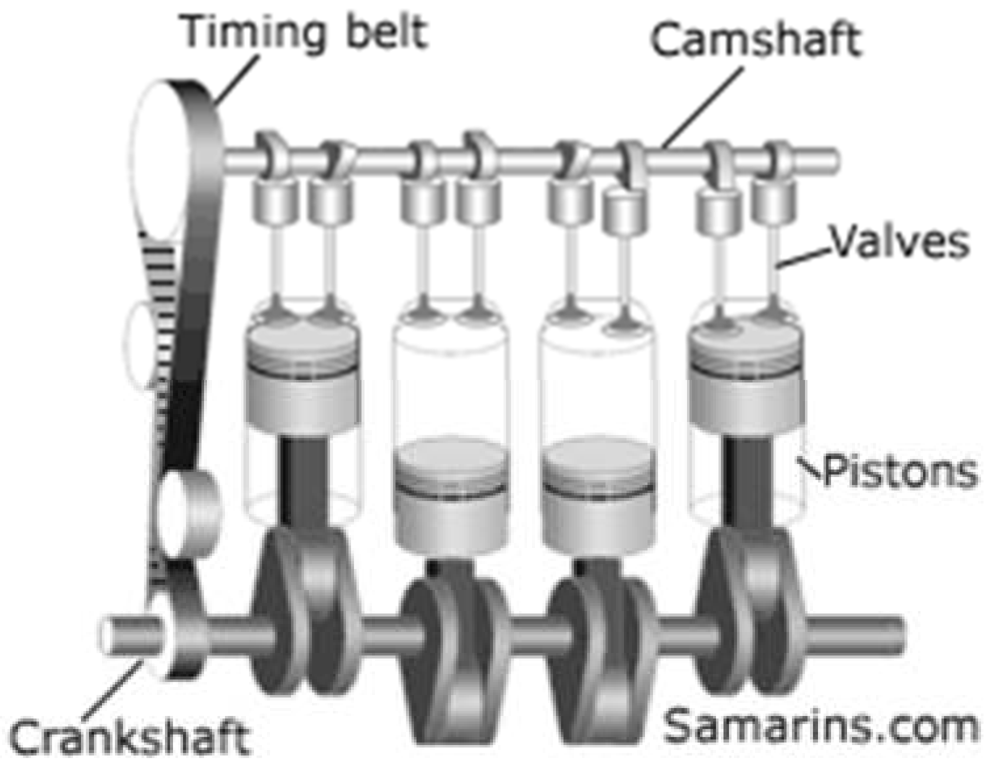
Overhead Valve Design (OHV)



Overhead Camshaft

- Camshaft is located in the cylinder head
- Driven by a belt or chain
- No pushrods
- May use rocker arms
- Can be a single cam or dual overhead cams

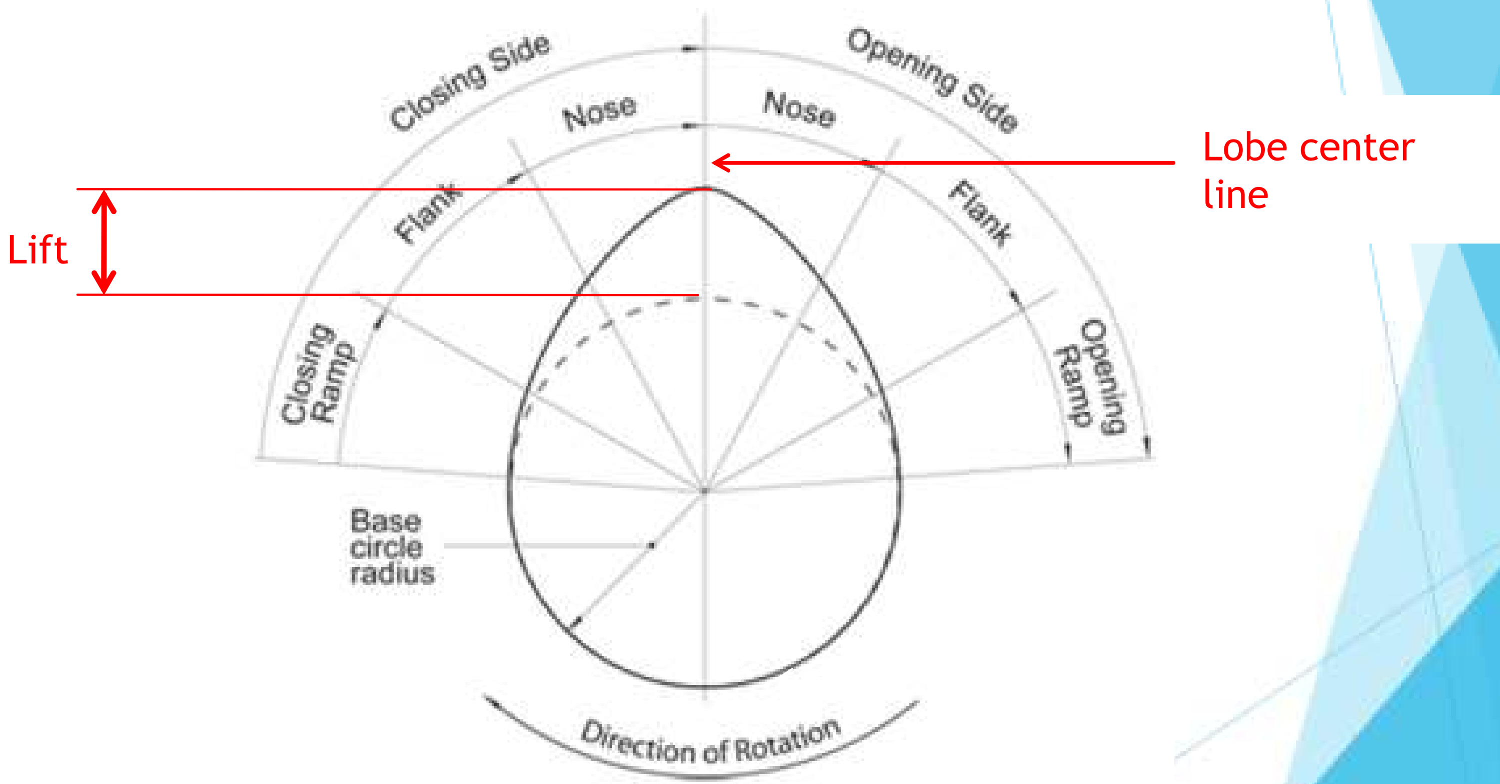
Single overhead camshaft (SOHC)



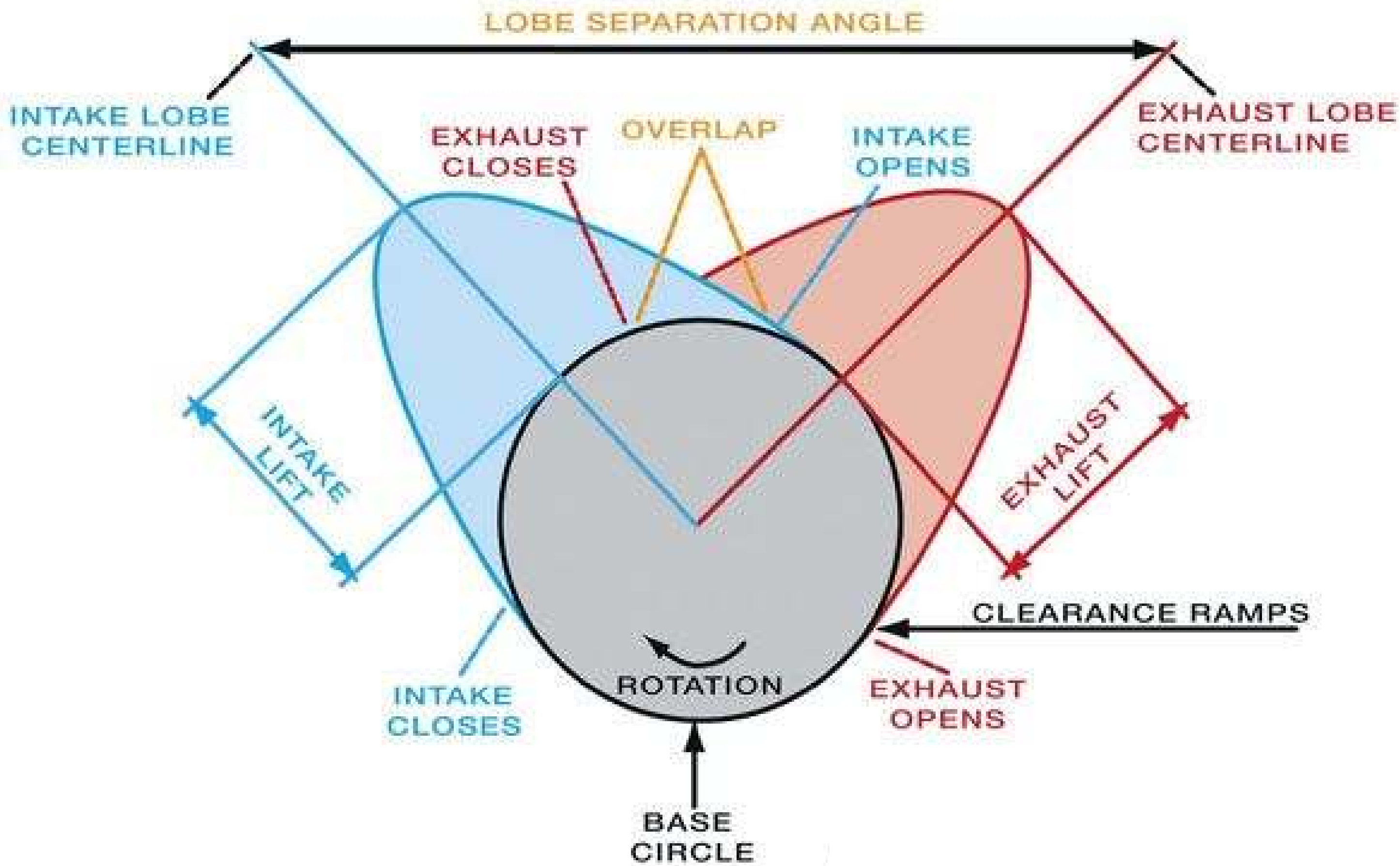
Camshaft Specifications Terminology

- Lift – the distance the valve is lifted off the valve seat, measured in decimal inches
  - More lift = more air fuel mixture is drawn in
- Duration – the amount of time the valve is off of its seat, measured in crankshaft degrees
  - Usually measured at .050 inch lift
- Lobe centers – the angle between the centerlines of the intake and exhaust lobes (AKA: lobe separation angle)
- Overlap – the number of degrees that both valves are open near TDC
  - Greater overlap causes rougher idle

Lobe Terminology

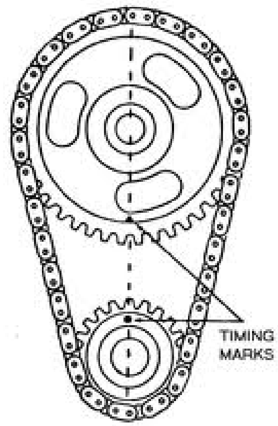


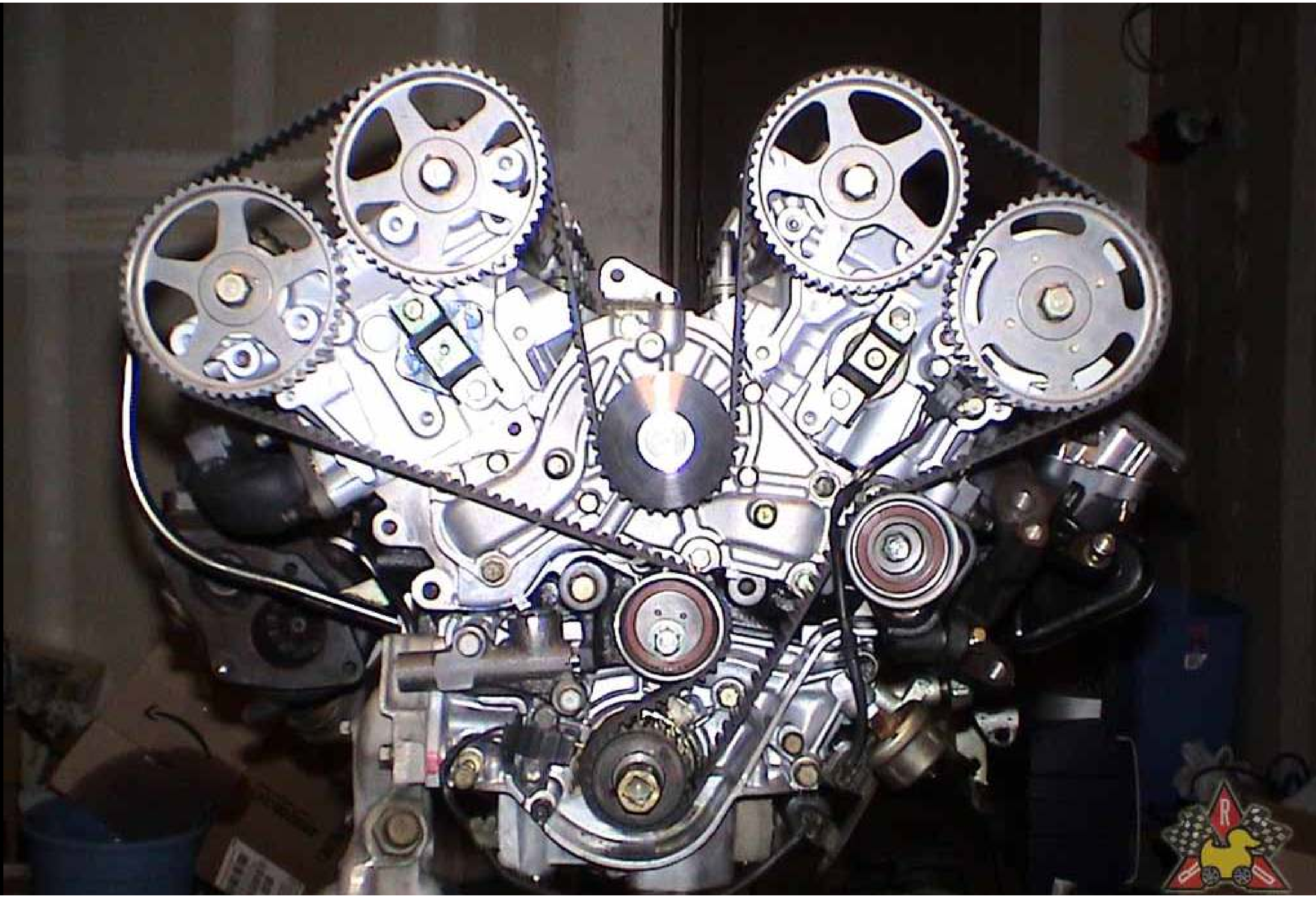
Separation between intake lobe centerline and exhaust lobe centerline is called Lobe Separation Angle


LOBE SEPARATION ANGLE
INTAKE LOBE CENTERLINE
EXHAUST CLOSES
OVERLAP
INTAKE OPENS
EXHAUST LOBE CENTERLINE
INTAKE LIFT
EXHAUST LIFT
CLEARANCE RAMPS
INTAKE CLOSES
ROTATION
EXHAUST OPENS
BASE CIRCLE

Camshaft Synchronization

- The cam shaft must be synchronized with the crankshaft to have correct valve timing
- Accomplished by lining up timing marks on timing gears
- Speed relationship: Crankshaft turns twice (720 degrees) for one revolution of the camshaft.



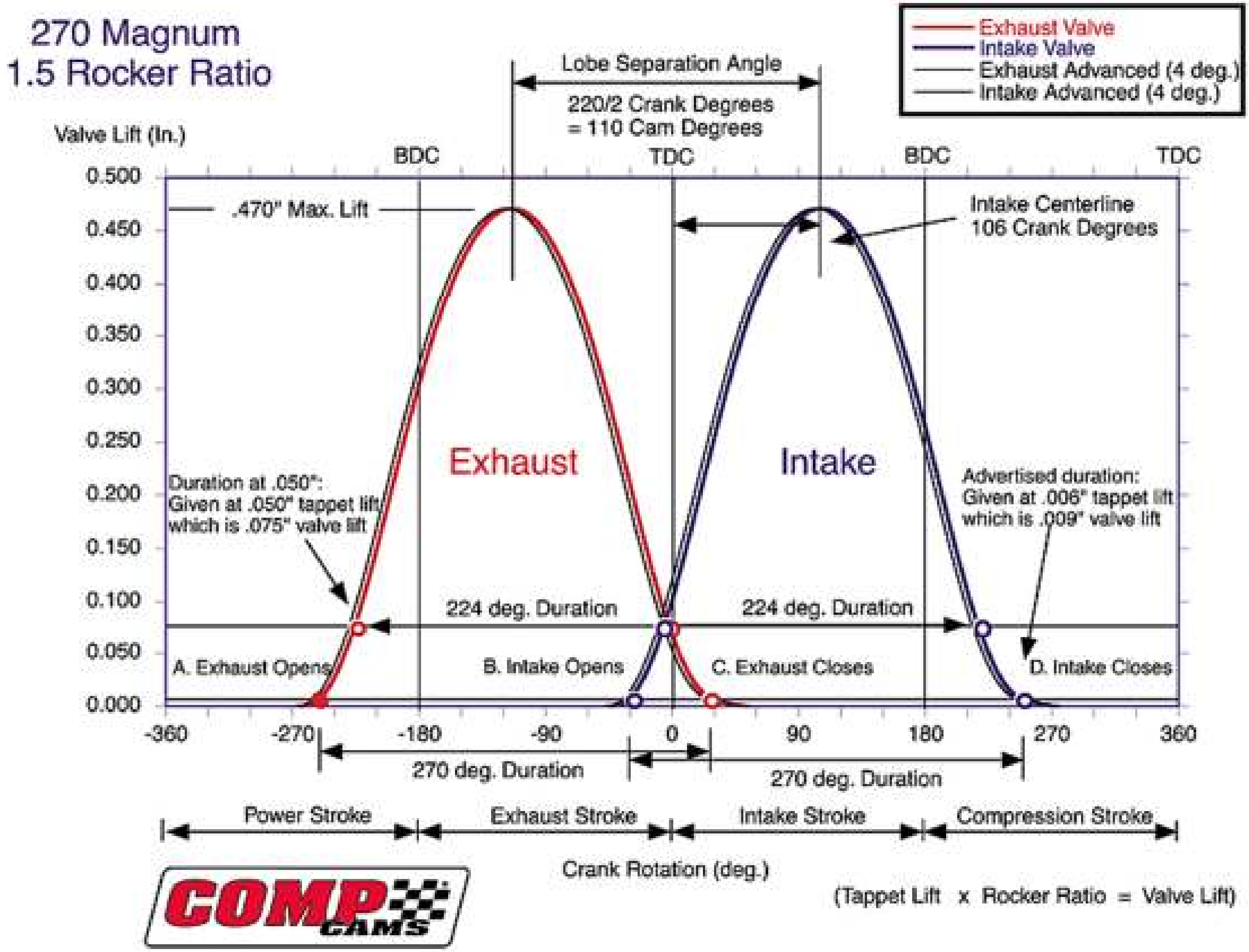


Valve Timing Events Acronyms

- TDC: Top Dead Center
  - BTDC: Before TDC
  - ATDC: After TDC
- BDC: Bottom Dead Center
  - BBDC: Before BDC
  - ABDC: After BDC

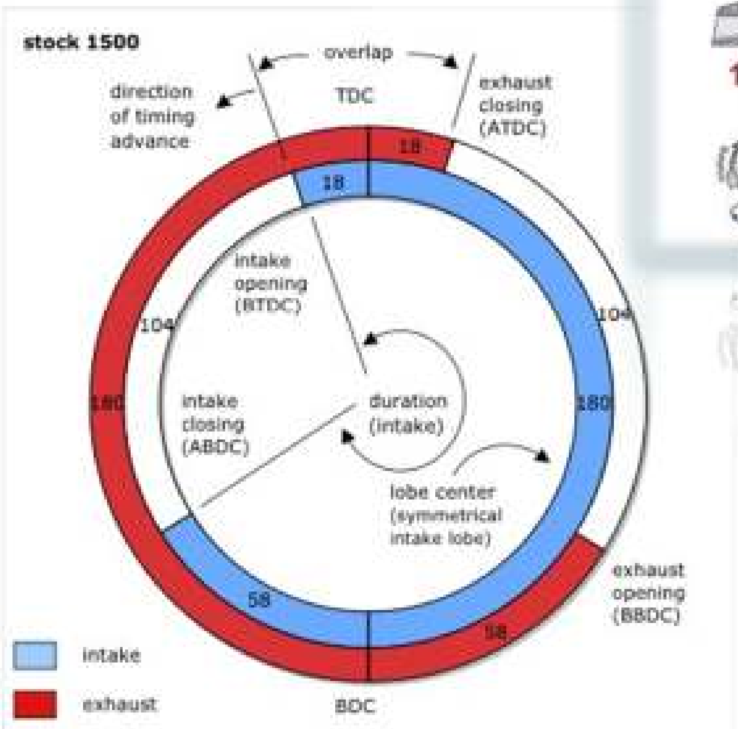
Valve Overlap

- Both intake and exhaust valve are open at same time near TDC
- End of exhaust stroke and beginning of intake stroke
- Improves volumetric efficiency by scavenging effect of exhaust
- Increasing overlap results in reduced idle quality, but better top end performance

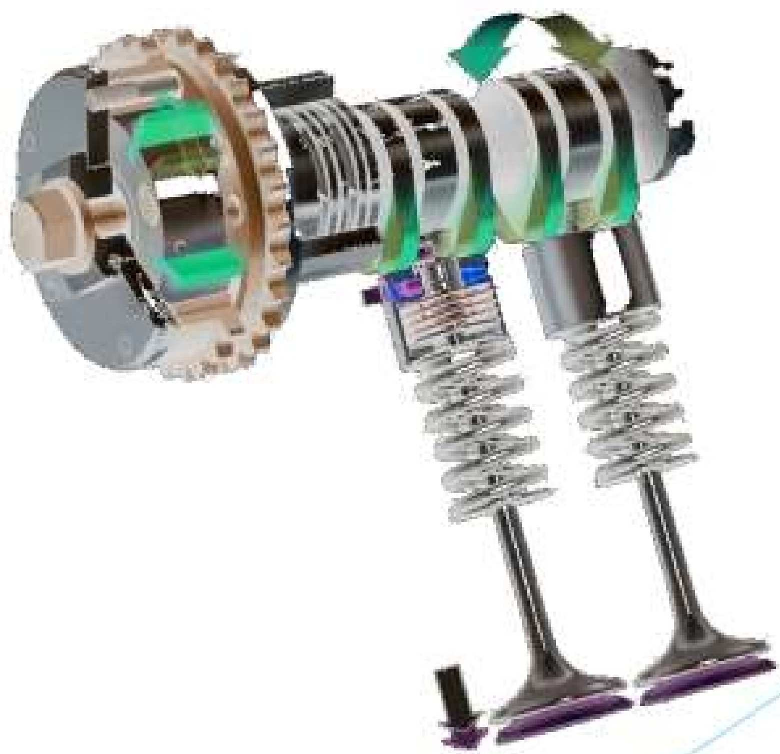

270 Magnum
1.5 Rocker Ratio
Exhaust Valve
Intake Valve
Exhaust Advanced (4 deg.)
Intake Advanced (4 deg.)
Lobe Separation Angle
220/2 Crank Degrees
= 110 Cam Degrees
Valve Lift (In.)
BDC
TDC
BDC
TDC
0.500
0.450
0.400
0.350
0.300
0.250
0.200
0.150
0.100
0.050
0.000
.470" Max. Lift
Intake Centerline
106 Crank Degrees
Exhaust
Intake
Duration at .050":
Given at .050" tappet lift
which is .075" valve lift
Advertised duration:
Given at .006" tappet lift
which is .009" valve lift
224 deg. Duration
224 deg. Duration
A. Exhaust Opens
B. Intake Opens
C. Exhaust Closes
D. Intake Closes
-360
-270
-180
-90
0
90
180
270
360
270 deg. Duration
270 deg. Duration
Power Stroke
Exhaust Stroke
Intake Stroke
Compression Stroke
Crank Rotation (deg.)
(Tappet Lift x Rocker Ratio = Valve Lift)
COMP CAMS


TDC
COMP
CAMS

VALVE OVERLAP



Variable Valve Timing Variable Valve Lift



Variable Valve Timing (VVT)

- Allows the *lift*, *duration* or *timing* of the valve opening to be changed while the engine is in operation
- Advantages:
  - Better performance through out the entire RPM range
  - Better fuel economy (5-10%)
  - Reduced NOx emissions
  - Eliminates EGR

Why is valve timing so important?

- One intake stroke takes approximately 34ms @ 700 RPM.
- When engine speed is increased to 2100 RPM the time is reduced to 11.4ms
- At even higher RPM it could be 3.4ms or less
- The problem is that the ideal valve action for 34 milliseconds will not be ideal for the valve action at 3.4 milliseconds because the cylinder will not have enough time to fill with air.
- If the cylinders do not fill completely with air at high RPM, Volumetric Efficiency is reduced and that reduces power.

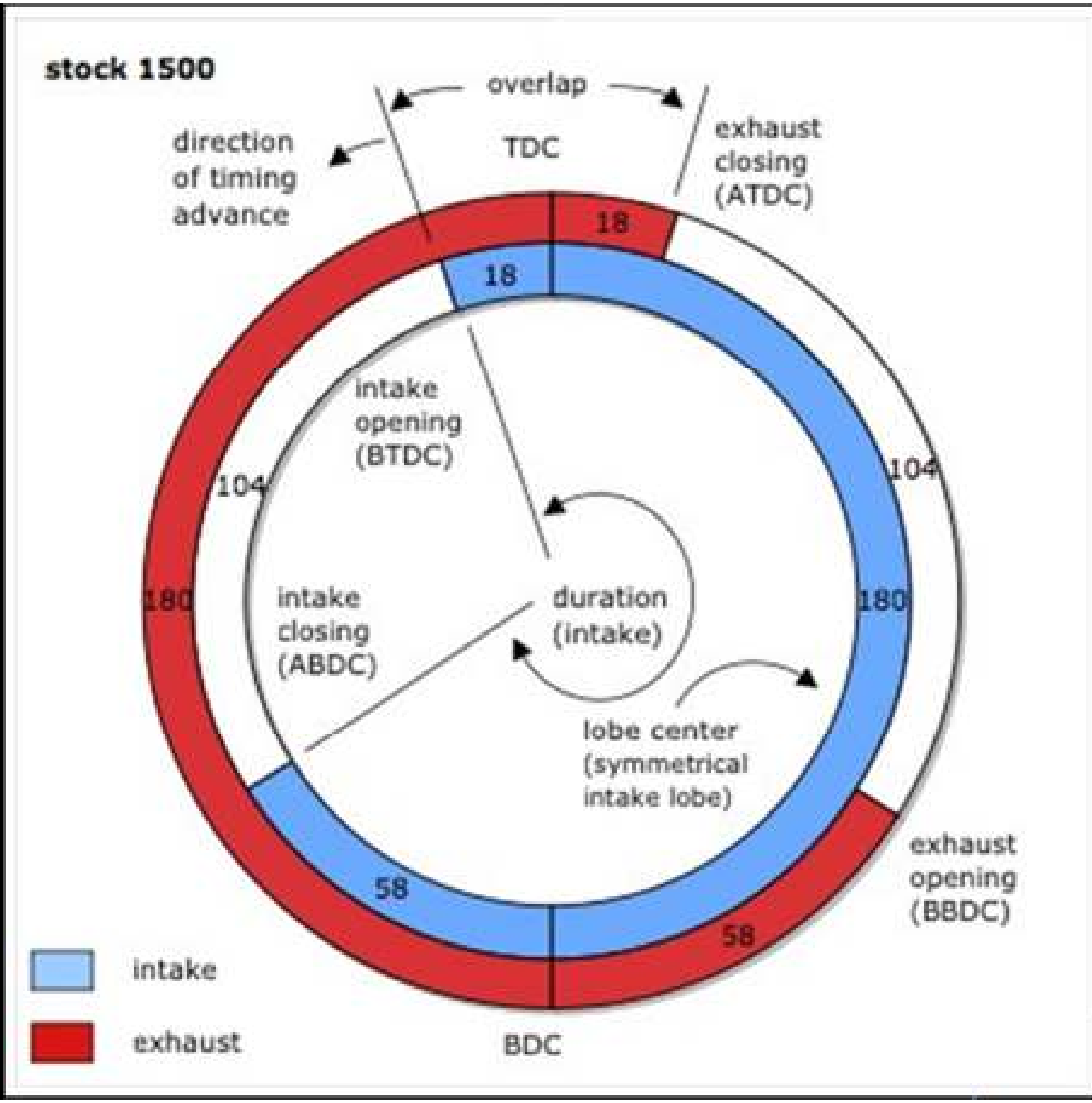
Remember the days of a HP cam where the vehicle would lope at idle, but at top end it would really have some power.

Cam design has always been a compromise.

To get max torque and power at high speed, cam designs would cause idle rough.

If the vehicle idled smooth, it would not rev to 7,000 RPM.

By the way, What caused that lumpy idle?


stock 1500
overlap
direction
of timing
advance
TDC
exhaust
closing
(ATDC)
18
18
intake
opening
(BTDC)
104
104
180
180
intake
closing
(ABDC)
duration
(intake)
lobe center
(symmetrical
intake lobe)
exhaust
opening
(BBDC)
58
58
intake
exhaust
BDC

Volumetric Efficiency

- The amount of fuel mixture drawn into the cylinder is determined by the engine size and volumetric efficiency (VE).
- VE is directly related to valve train operation.

What is Volumetric Efficiency?

- The actual amount of air flowing through an engine, compared to the engine's displacement
- For example: a 350 CID engine should draw in 350 cubic inches of air when every piston makes one intake stroke.
- It's a measure of how full the cylinders get, expressed as a % of how full they should get determined by the displacement of the engine
- An engine operating at 100% VE is using all of its volumetric capacity.
- An engine is a breathing machine, the more air it can take in and exhaust out, the more power it will make.

Volumetric Efficiency

- At a 700 RPM idle an engine should have 100% efficiency because the piston has 34ms on the intake stroke, to draw air in; plenty of time to fill the cylinders with air.
- As RPM increases this time decreases, but the area for the air to enter the cylinder remains the same.
- The ideal valve action at idle (34ms) is not the ideal for the valve action at high RPM (3.4ms or less)
- We measure VE at engine red line, under load, so a naturally aspirated engine will be less efferent at high RPM because the cylinders will not completely fill with air.
- This is where variable valve timing gets interesting, it improves VE as RPM increases by changing the overlap, without affecting idle quality.
- Result smooth idle + high performance redline

Valve Timing and Overlap

- The timing of air intake and exhaust is controlled by the lobe shape and phase angle of the lobes
- As previously stated, an engine requires different valve timing at different speeds for optimum performance
- Ideally intake valves open earlier and the exhaust valves close later
- Overlapping between intake and exhaust should be increased as RPM increases

Ignition Timing vs. Valve Timing

- Ignition timing synchronizes the time the spark plug fires to the location of the piston, in relation to TDC
- Valve timing synchronizes the opening and closing of the intake and exhaust valves in relation to the location of the piston to TDC
- Ignition timing is controlled by spark advance or retard adjustment
- Valve timing is controlled by camshaft design (Before VVT)

FreeValve

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