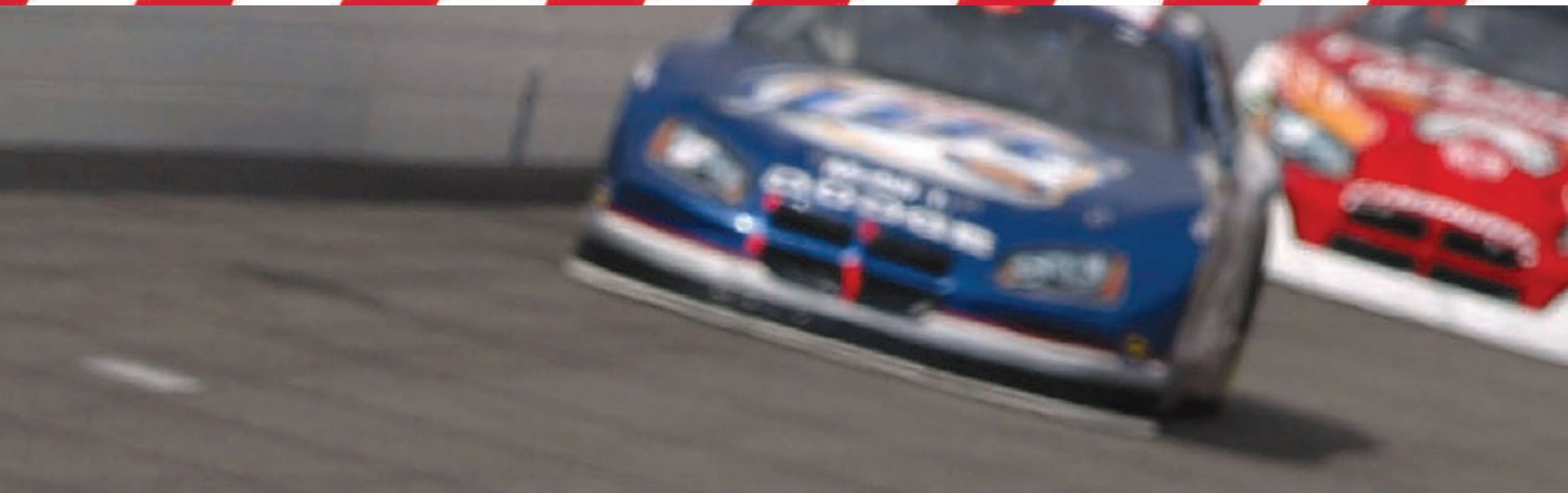


The Science of NASCAR

By Brian Rohrig

Drivers, start your engines!

As the green flag descends, 43 cars emblazoned with multicolored decals accelerate to race speed amid the deafening roar of thousands of fans. The smell of rubber permeates the air as the drivers immediately jockey for position. Only one driver will emerge victorious when the checkered flag lowers a few hours and several hundred miles later.

Welcome to NASCAR—the uniquely American sport. NASCAR stands for the National Association for Stock Car Auto Racing, and it began in 1947. NASCAR has exploded in popularity in recent years. It is a dangerous and exhilarating sport. The cars are loud and fast. The drivers are as popular as movie stars. And underneath the hood of every car, chemical reactions are occurring at a furious pace.

The drivers and mechanics who work daily with these cars thoroughly understand the science behind them. And to make things even more challenging, the rules change constantly, sometimes weekly. These constant rule changes force race teams to modify their cars accordingly. And on top of that, each NASCAR track is different, creating the need for adjustments to be made to the car, depending on the challenges of each particular track.

The skeleton of every NASCAR car is the frame. The frame is tubular and is purchased prefabricated from the manufacturer. It is made of steel tubing—some round and some square. The thickness can vary, but the thickest part surrounds the driver and comprises the roll cage, which protects the driver in case of a collision. The front and rear tubing the thinnest and designed to crush in case of a collision. This protects the driver, as the collapsible frame absorbs the bulk of the energy of a collision, as opposed to the driver. The frame is also designed to force the engine downward and onto the ground in case of a severe collision, and not into the driver.

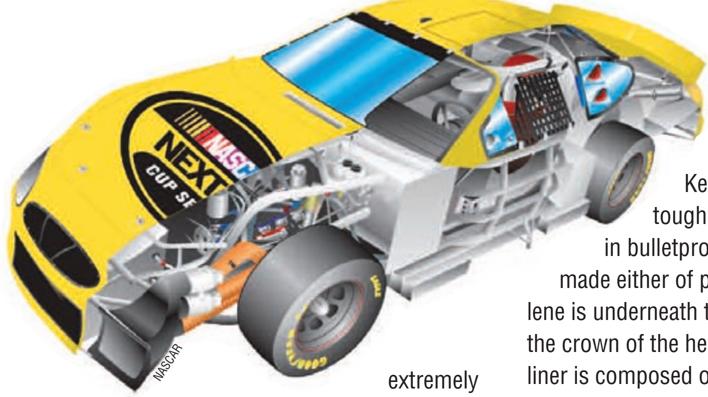
Every NASCAR car has a few stock parts—hence the name stock car—but these are strictly cosmetic. A stock part is a part that is made in an assembly line by the manufacturer. The only stock parts are the hood, roof, trunk lid, and front grill. The rest of the car is custom made. Each NASCAR car must use stock parts exclusively from one of the following: Chevrolet Monte Carlo, Ford Fusion, Pontiac Grand Prix, or Dodge Charger. Beyond that, the cars bear little resemblance to their namesakes.

A NASCAR car contains no glass, no doors, no back or passenger seats, no headlights, no brake lights, no speedometer, no gas gauge, no muffler, no stereo, no air conditioning, no glove compartment, no horn, and no air bags! Instead of headlights, stickers are affixed to the front of the car to resemble its parent stock car. The steering wheel is detachable, making it easier to enter and exit the car. You do not need a key to start a NASCAR race car—you simply flip a switch and the engine roars to life.

Playing it safe

Safety is paramount in the construction of every feature of a NASCAR automobile. The windshield is made of Lexan, a very soft but

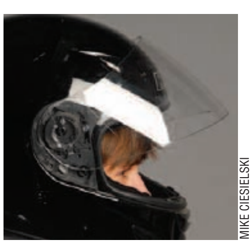
THE UAW-DAIMLERCHRYSLER 400 NASCAR NEXTEL CUP SERIES RACE AT LAS VEGAS MOTOR SPEEDWAY. GETTY IMAGES FOR NASCAR



extremely durable material. It is so soft that it can be easily dented or scratched, but it will not shatter. It is covered with layers of thin adhesive transparent film to prevent it from being damaged during a race. If a layer of film becomes scratched or dirty during the race, it can be quickly peeled off during a pit stop. Lexan is made from a thermoplastic polymer known as polycarbonate. Thermoplastics soften upon heating. Lexan is also used to make iPods, CDs, and DVDs, and the sturdy water bottles used by hikers. It is so strong that it is the chief component of bulletproof glass!

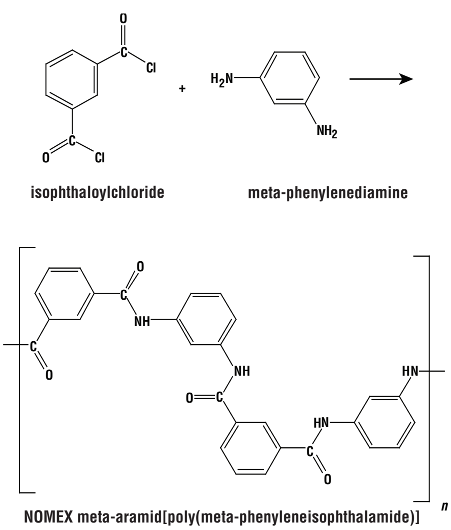
On the driver's side is nylon webbing in place of a window, which is designed to keep the driver's hands and arms inside the car during a collision. It is equipped with a quick-release mechanism in case a quick exit from the car is required.

All drivers must wear a helmet, which is specially designed for them, and is designed to protect their head in case of an accident.



Cockpit showing head and neck support device.

Racing helmets are made of three main parts. The hard outer shell is coated with a composite of carbon, glass and Kevlar. Kevlar is an extremely tough polymer that is also used in bulletproof vests. A foam liner made either of polystyrene or polypropylene is underneath this layer, and is found in the crown of the helmet. The form-fitting inner liner is composed of either nylon or Nomex, a fire-resistant material. Nomex is also used in firefighters' gear and will not burn even if soaked in gasoline! The chinstraps are made of Kevlar, and the visor is made from Lexan. All helmets are designed to withstand 300 Gs of force.



Synthesis of NOMEX

Drivers are held in place with a five-point harness, similar to that found in a child's car seat. The seats hug the body and are custom made for each driver. They protect the driver's rib cage during an accident. Some seats wrap around a driver's shoulders as well.

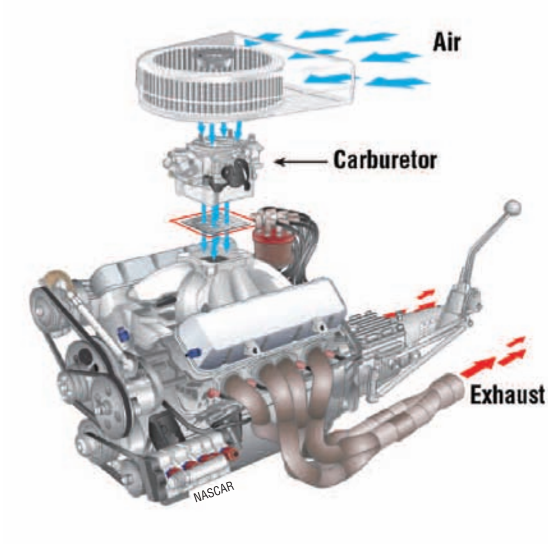
After the tragic death of legendary driver Dale Earnhardt in the 2001 Daytona 500, NASCAR mandated the use of a head and neck support (HANS) device to further protect the driver. Earnhardt died due to a fracture at the base of the skull after a 180 mph head-on collision into the wall during the last lap of the race. Earnhardt's death could possibly have been prevented if he had been wearing such a device.

The gas tank—fuel cell in NASCAR terminology—generally holds 22 gallons of gasoline. It is composed of an inner elastic bladder made of a thermoplastic elastomer surrounded by an outer layer of steel. The term *elastomer* is often used interchangeably with the term *rubber*. Elastomer comes from two terms: *elastic* (describing the ability of a material to return to its original shape when a load is removed) and *mer* (from polymer, in which *poly* means *many* and *mer* means *parts*). The tank is filled with polyurethane foam, which prevents the fuel from sloshing around. In case of an explosion, the foam would absorb some of the impact. In case a car does burst into flames, the driver is protected. All drivers wear fire-retardant long underwear, as well as a fire-resistant jumpsuit and gloves made from Nomex.

Most cars are equipped with a cooling system that blows cool air into the driver's helmet and over his body. Sometimes, dry ice (solid carbon dioxide) is used in the car, which greatly increases the rate of cooling of the air flowing over it. This constant stream of air cools the driver through the endothermic process of evaporation. Evaporation of water absorbs energy, so when sweat evaporates, it removes energy from the skin, creating a cooling effect. Sweating does not cool you if it cannot evaporate, explaining why it feels so uncomfortable during days of high humidity when little evaporation can occur because the air is already saturated with water vapor. Without these cooling systems, temperatures could easily reach 150 °F (66 °C) within a car during a race.

The engine

The soul of every NASCAR car is its engine. NASCAR cars have 8 cylinders, as do the largest and most powerful passenger vehicles. A cylinder is a space within an engine where the piston moves up and down. You can tell how many cylinders an engine has by the number of spark plugs. Each cylinder contains one spark plug. If the 8 cylinders are arranged in a "V" pattern, the engine is a V-8



Eight-cylinder V8 engine.

(which has nothing to do with the vegetable juice). The V shape is designed to reduce engine vibration, as the vibrations that the pistons produce are cancelled out through destructive interference. The V shape maximizes this destructive interference, thus reducing engine vibration.

The volume of each cylinder is known as its displacement. You may recall from your geometry class that the volume of a cylinder is found by the formula $V = \pi r^2 h$. By adding up the total volume of all the cylinders in the car, the total displacement of the engine is determined, which is commonly referred to as the engine size. A typical NASCAR car has an engine displacement of anywhere from 5735 cc to 5867 cc (350 to 358 cubic inches). That means each cylinder has a displacement of 717–733 cc—a little smaller than a 1-L bottle.

1 cubic centimeter = 1 cc = 1 cm^3 = 1 mL

Within each cylinder is a piston, which is a rounded piece of cylindrical metal specially fitted to move up and down rapidly within the cylinder. As the cylinder moves upward, any gases within the cylinder are compressed. As the cylinder moves downward, the gases within the cylinder expand. Boyle's Law states that as the pressure on a gas increases, its volume decreases, and likewise as the pressure on a gas decreases, its volume increases.

Attached to a piston is a connecting rod, which is attached to the crankshaft. The crankshaft rotates very quickly. So the up-and-down motions of the pistons are converted into the rotational motion of the crankshaft, which is what ultimately causes the tires to spin. The faster the pistons move up and down, the faster the crankshaft rotates. And the faster the crankshaft rotates, the faster your car goes. So to get a 3400 lb (1545 kg) NASCAR race car up to a speed of 200 mph (321 kilometers per hour), those pistons must be moving up and down very fast.

Burn, baby burn

What causes the pistons to move up and down within the cylinders? That's where chemistry comes into place. A mixture of fuel and air within each cylinder is ignited by a spark from the spark plug. As the fuel combusts, it undergoes a chemical reaction, yielding gaseous byproducts. Gasoline can only burn if it is in the vapor state; technically, liquid gasoline doesn't burn, it is the vapor above the liquid that burns. The chemical equation for the combustion of the octane within gasoline is as follows:

$$2\ C_8H_{18(g)} + 25\ O_2 \rightarrow 16\ CO_{2(g)} + 18\ H_2O_{(g)}$$

The reaction is also highly exothermic, causing these gases to expand greatly. This expansion pushes against the piston, causing it to move downward. Each of the following eight cylinders will then fire, and once all eight cylinders fire, the process repeats itself over again. These cylinders fire hundreds of times per minute, in rapid succession. NASCAR cars do not have a muffler, explaining why they are so loud. If the exhaust has to pass through a muffler, it takes longer to exit the car, reducing the amount of power.

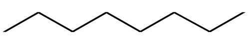
An average pit stop involving the changing of all four tires and a full tank of fuel can take between 13 and 15 seconds.

Don't come knocking

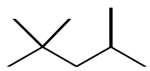
What type of fuel do these engines use? Unlike Indy race cars, which use pure methanol (CH_3OH), NASCAR race cars use gasoline, but not the same type that your car uses. They use leaded 110-octane gasoline. The lead is in the form of a compound known as tetraethyl lead ($Pb(CH_2CH_3)_4$), which reduces engine knocking. Knocking is the loud, metallic clanging that accompanies preignition of fuel in the cylinders before the proper time. Under certain conditions, as gas is compressed in the cylinder, it may ignite before the spark plug fires. A small amount of $Pb(CH_2CH_3)_4$ improves the performance of the gas, preventing it from igniting as it is compressed. Before the 1970s, almost all of the gas in the United States was leaded, but $Pb(CH_2CH_3)_4$ is now outlawed in the United States and many other countries as a gasoline additive because it is an environmental contaminant that has been linked to a wide range of neurological and other disorders (*ChemMatters*, **1983** Vol. 1(4)). NASCAR officials have announced a plan to switch to an unleaded high octane formulation by 2008.

The octane rating you see posted on a gas pump such as 93 Octane or 87 Octane is determined by a formula that represents the average resistance of the gas to engine knock. Another way to look at it is the rating tells you how much the fuel can be compressed before it will spontaneously ignite. The higher the octane rating, the more gas can be compressed in the cylinders before ignition. The more fuel is compressed, the more fuel is burned per unit time, which means more energy is released, and that means more *power*!

Octane, C_8H_{18} (sometimes called *n*-octane or normal octane), is a hydrocarbon that can be compressed fairly well without igniting. Isooctane, an isomer of octane, is even better at being compressed without igniting, so it is used in regular gasoline and is given the value of 100 in the octane rating system.

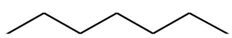


***n*-octane (C_8H_{18})**



isooctane (C_8H_{18})

The other major component of gasoline is *n*-heptane, and it is assigned an octane rating of 0. An octane rating of 87 means the mixture has the same resistance to preignition or that it will burn as rapidly as a mixture of 87% isooctane and 13% *n*-heptane.



***n*-heptane (C_7H_{16})**

Why does isooctane resist preignition better than octane? Well, isooctane is a more stable compound than octane, so the combustion of isooctane requires greater activation energy than for *n*-octane. Therefore, isooctane is less likely to ignite due to increased pressure alone.

So how in the world can race cars use a fuel with an octane rating of 110? Does this mean you can have 110% isooctane in your fuel? That would be impossible! This high octane rating refers to the performance of the gasoline compared to 100% octane. 110-octane fuel gives a performance 10% better than fuel containing 100% octane by using a high percentage of isooctane and a combination of other additives, including tetraethyl lead.

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Tires

Tires play an integral role in any NASCAR race. A typical car can go through 40 tires in one race! The tires are very thin—only about a quarter of an inch thick. If they were any thicker, they would get too hot due to friction between the tire and the track and would melt. Another difference between these tires and normal passenger tires is that NASCAR tires have no tread. They are completely smooth. The smooth surface means more surface area is in contact with the road, producing better traction. The tires actually become so hot that they do melt slightly, becoming sticky, which further increases traction.

The tires are often underinflated when they are first installed on a car, and after a few laps, the tires heat up and the pressure becomes greater. Tires can experience an increase in pressure of 10–20 psi (pounds per square inch) during a race! This is in accordance with Gay-Lussac's Law, which states that the pressure of a gas increases as its temperature increases. As the temperature goes up, the kinetic energy of the particles increases, which increases the number of collisions and thus the pressure. Even when hot, the tires will generally be under lower pressure than you will find on a typical passenger car, so as to increase the surface area of the tire in contact with the road, further increasing its grip. Because the tires have no tread, a typical NASCAR race cannot be held in the rain or the cars would have no traction whatsoever.

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NASCAR

Goodyear Eagle Radial Race Tire
Tread Width: 11.5 inches
Average Life: 150 mi

Goodyear Eagle High-Performance Street Tire
Tread Width: 9 inches
Average Life: 50,000 mi

Another difference between NASCAR tires and normal tires is that NASCAR tires are filled with nitrogen, not normal air (Question From the Classroom, *ChemMatters* February 2006). Compressed nitrogen contains less moisture than normal air. As the tires become heated during the race, any moisture in the tire can vaporize and expand, causing a noticeable increase in tire pressure. Changes in tire pressure can greatly affect the handling of a car. Using normal air that has been dried is another way to reduce moisture content in the air, but this is more difficult to accomplish than just using compressed nitrogen. Despite these precautions, blowouts do occur. To prevent cars from careening out of control during a blowout, most NASCAR tires contain an inner liner than allows the car to make a controlled stop.

And the winner is ...

When the checkered flag lowers and the race is over, the winner will invariably thank his entire team for winning the race. Behind every driver is a successful crew. The chemistry between the driver and his crew is every bit as important as the chemistry that goes on under the hood.

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OTHER REFERENCES CAN BE FOUND IN THE TEACHER'S GUIDE FOR THIS ISSUE.

Brian Rohrig teaches at Jonathan Alder High School in Plain City, OH. His most recent *ChemMatters* article, "Thermometers," appeared in the December 2006 issue.

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