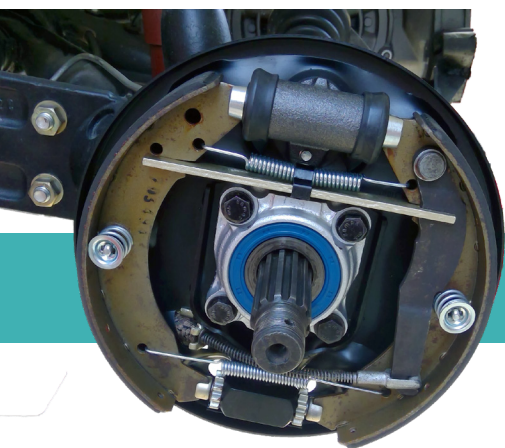


24



## #70- Brakes: brake assembly

*page 02*



## #71- Electrical: define cable diameter

*page 26*



## #72- Technical: metric bolts

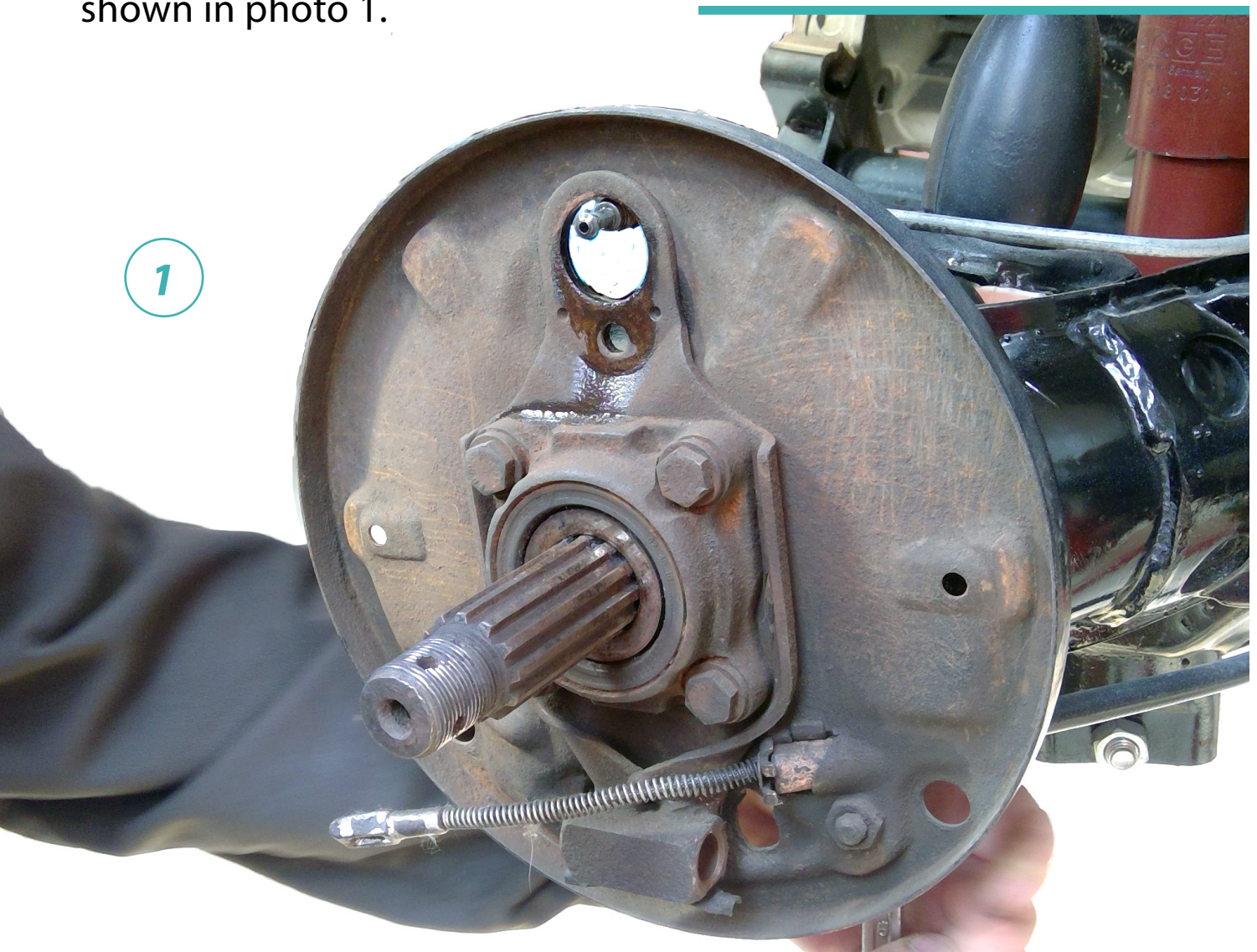
*page 42*



## Introduction

In [edition 23](#) we disassembled the rear brakes of our VW 1303. All classic Volkswagens were equipped with rear drum brakes, the procedure for other models than the 1303 is quite similar. If you followed along with the previous edition, you should see roughly what is shown in photo 1.

We went a little further than needed and replaced the brake backing plate as well. These on our VW 1303 were in bad shape, lots of corrosion and damaged inspection holes due to using a trivial screwdriver for adjustment (see [edition 23 page 23](#)).

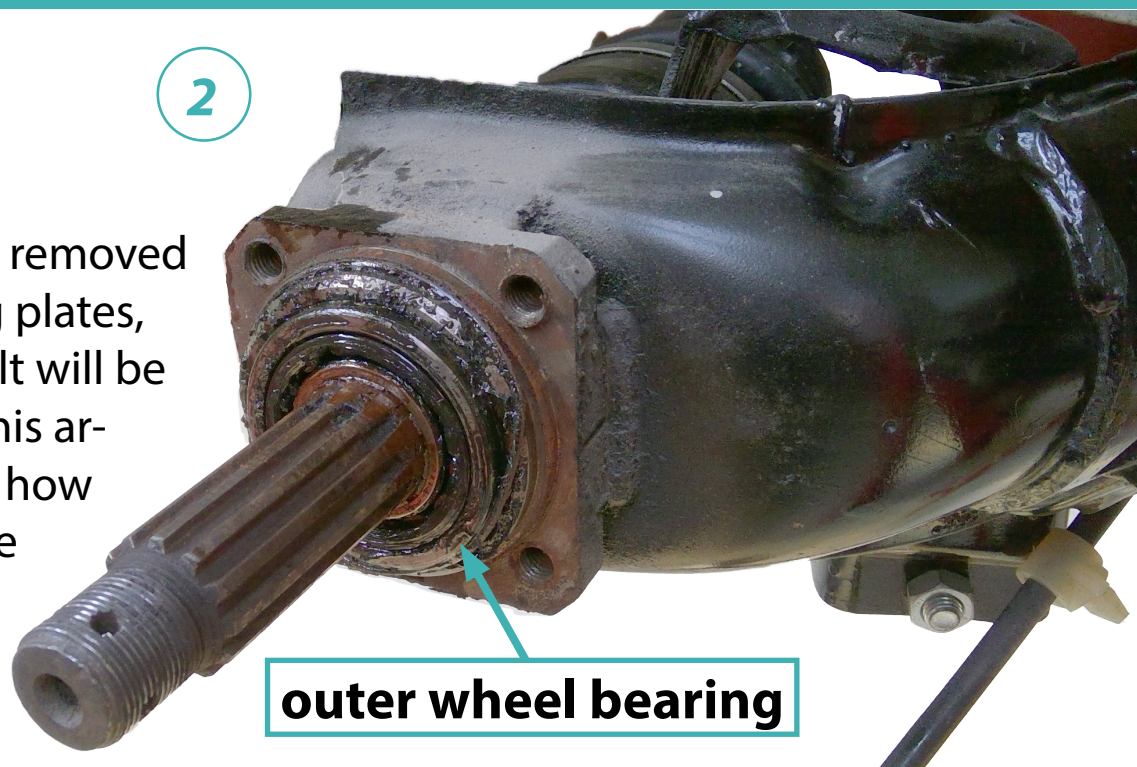




# rear brake assembly

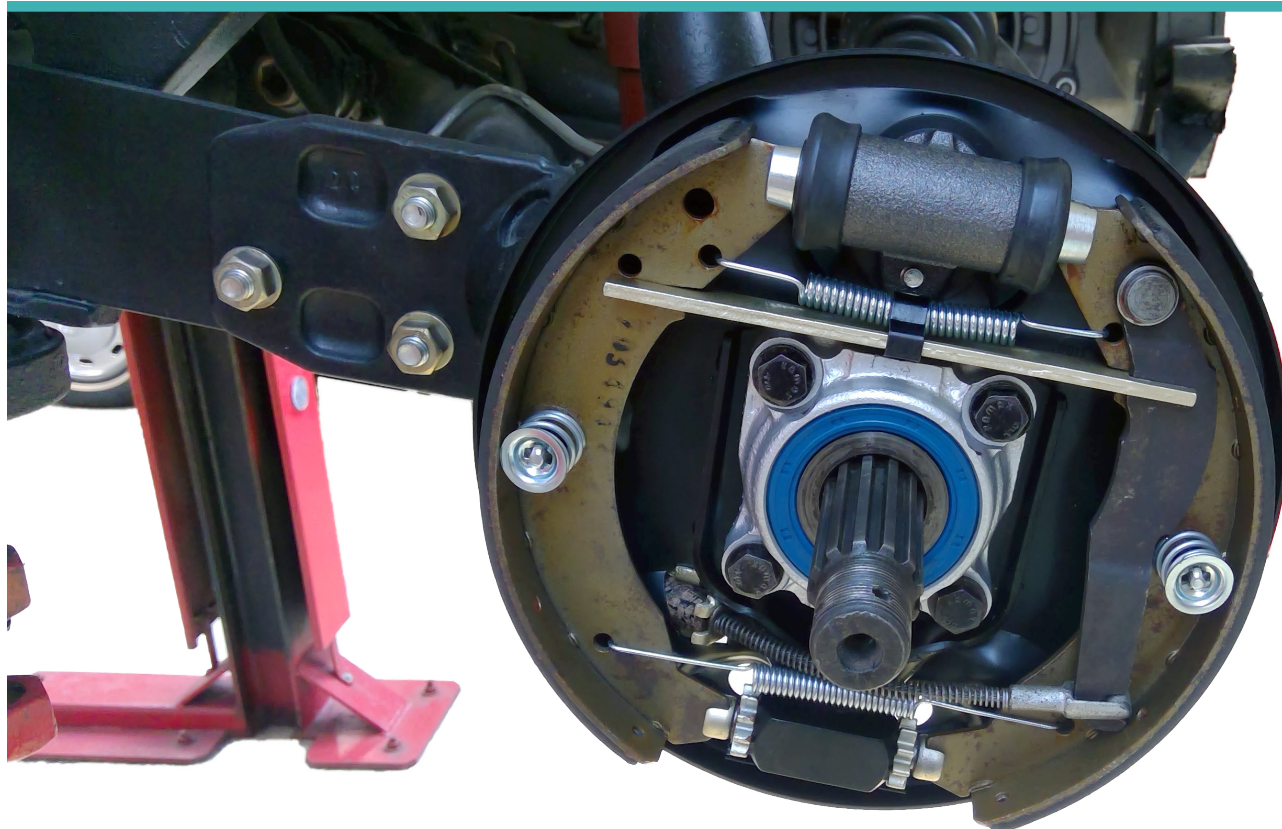
2

If, like us, you also removed the brake backing plates, then the end result will be like picture 2. In this article we will show how to assemble all the rear brake parts. In photo 3 we show the end result. We will show how to replace the rear wheel bearings in the next edition.



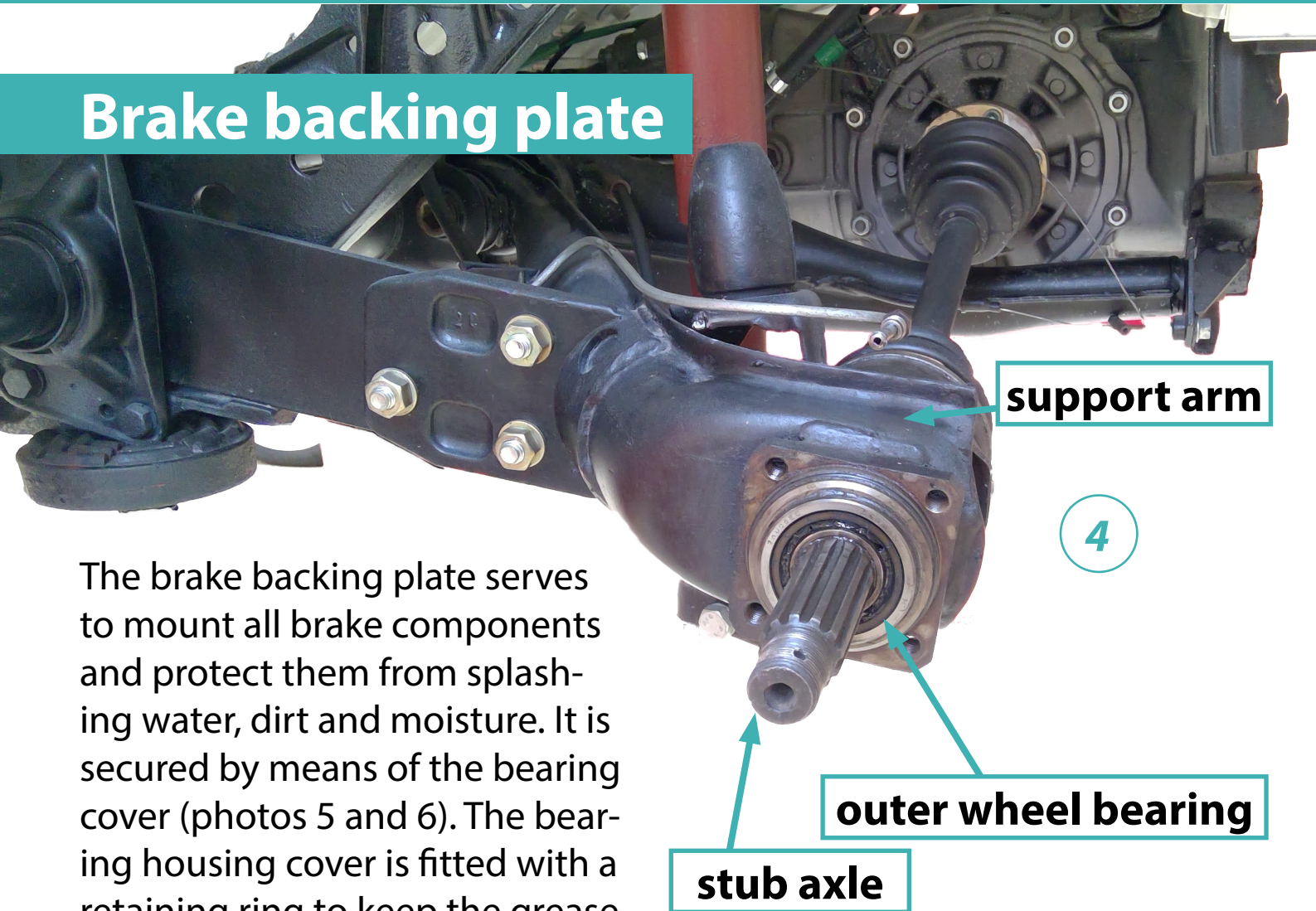
**outer wheel bearing**

3





## Brake backing plate



The brake backing plate serves to mount all brake components and protect them from splashing water, dirt and moisture. It is secured by means of the bearing cover (photos 5 and 6). The bearing housing cover is fitted with a retaining ring to keep the grease from the outer wheel bearing in (on an IRS transmission, on the swing axle it is the gearbox oil that must be stopped).

We are not replacing the rear wheel bearing in this edition, we will do that in edition 25. The wheel bearings of our VW 1303 showed no signs of wear or damage, just cleaning them with a lint-free cloth and reapplying

*In photo 4 the brake backing plate is not yet mounted, we won't do that until page 8.*

new wheel bearing grease was sufficient.

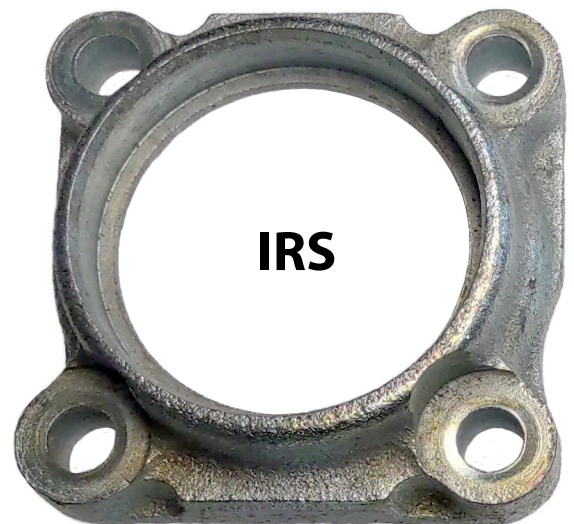
The photo above shows the starting point for this article, the support arm with stub axle and a clean outer wheel bearing.



# rear brake assembly

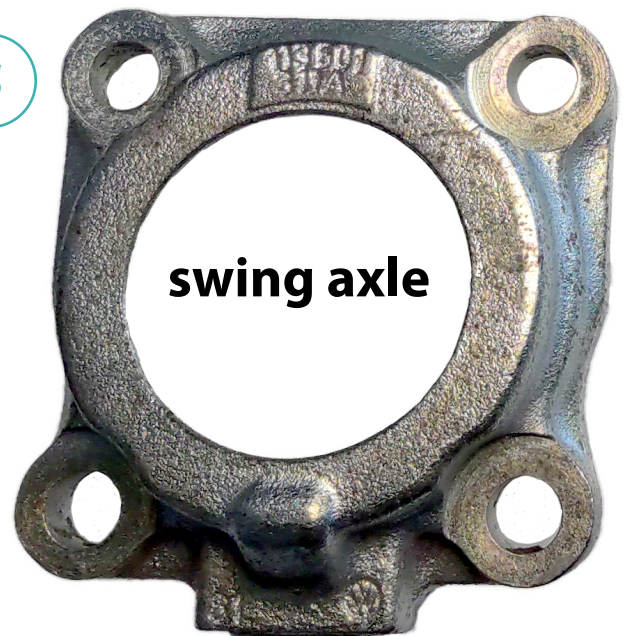
You don't really need to loosen the bearing cover if the wheel bearings are good, and if you don't see traces of transmission oil (in the case of a swing axle) or traces of bearing grease (in the case of an IRS). But it is not a bad idea to loosen the cover if you have a classic Volkswagen in front of you of which you do not know the maintenance history. With the swing axle, the wheel bearings are lubricated by the gearbox oil, if the oil seal leaks, it can have devastating consequences for your brake components. With the IRS, it's a little less so because it's thick wheel bearing grease that won't disperse as quickly.

5



**IRS**

6



**swing axle**

**oil drain**

7

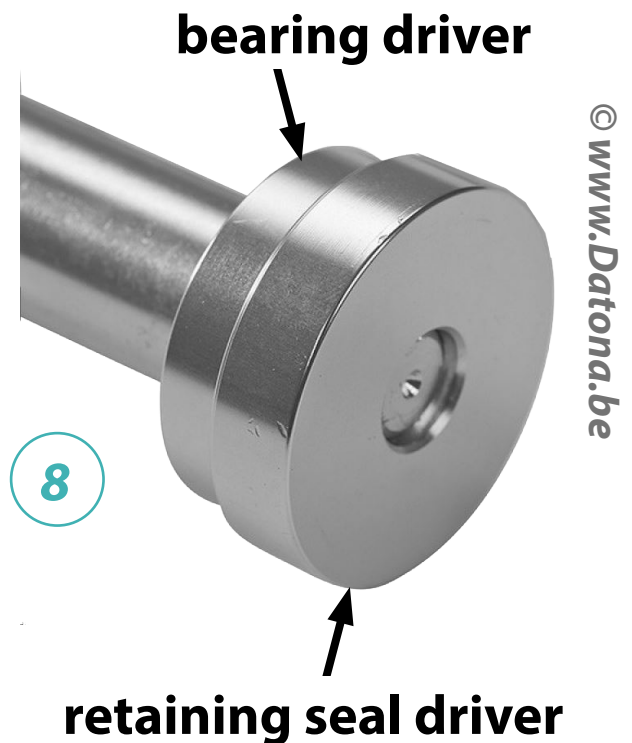
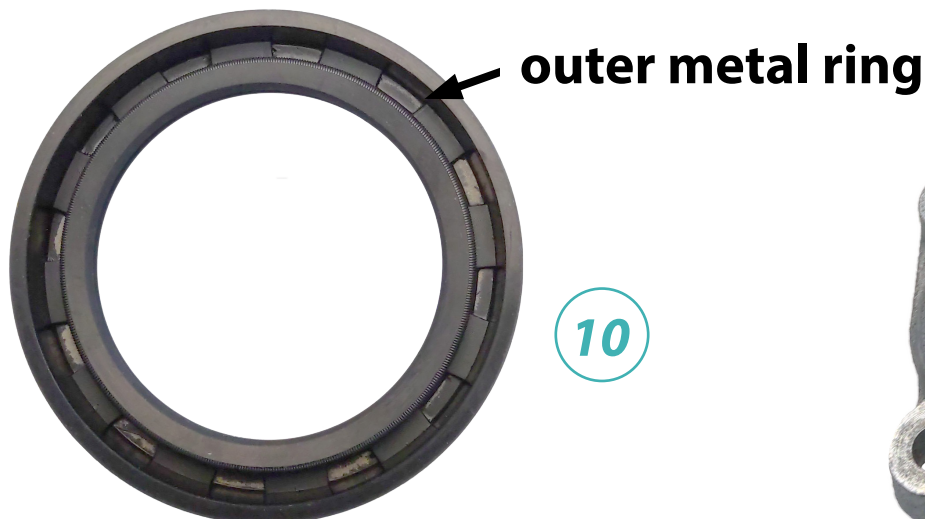


*For IRS rear wheel bearings, we recommend this universal grease (photo 7). In the case of swing axles, for rear axles that are at a standard height, the wheel bearings are lubricated by the gearbox oil that flows down through the axle pipe. If the swing axle is lowered, closed bearings lubricated with grease are recommended.*

Clean the bearing cover before assembly, we provide our VW 1303 with a new one as the old cover was in poor condition. Once cleaned, we provide the bearing cover with a new grease seal.

In [edition 21](#) we have already shown how to assemble a grease seal (retaining ring). You can use a suitable cap or a retaining seal driver (pictures 8 and 9). The retaining seal driver we used for our VW Beetle is 59 mm to 60 mm in diameter.

*Grease seals come in a variety of shapes and colors. The one for the outer bearing of the rear wheel was black in the webstore at the time of writing this article (photo 10), the one we had in stock in the workshop was blue (page 8). The color has no other technical significance. What is important is that the lip is mounted on the oil/grease side and that you only push against the outer metal ring (not the inner ring or lip).*



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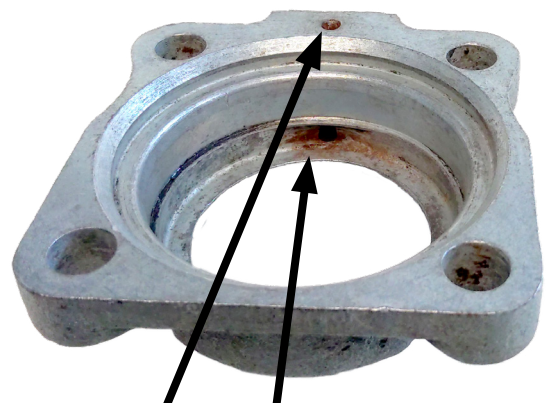




# rear brake assembly

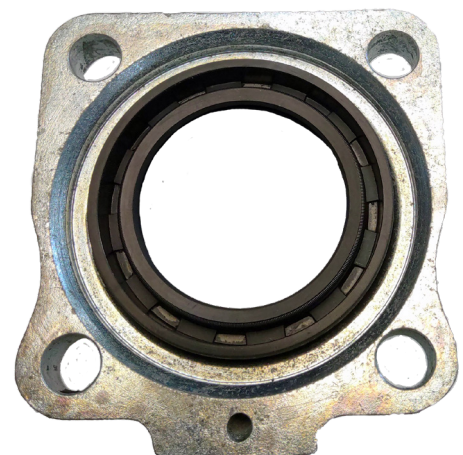
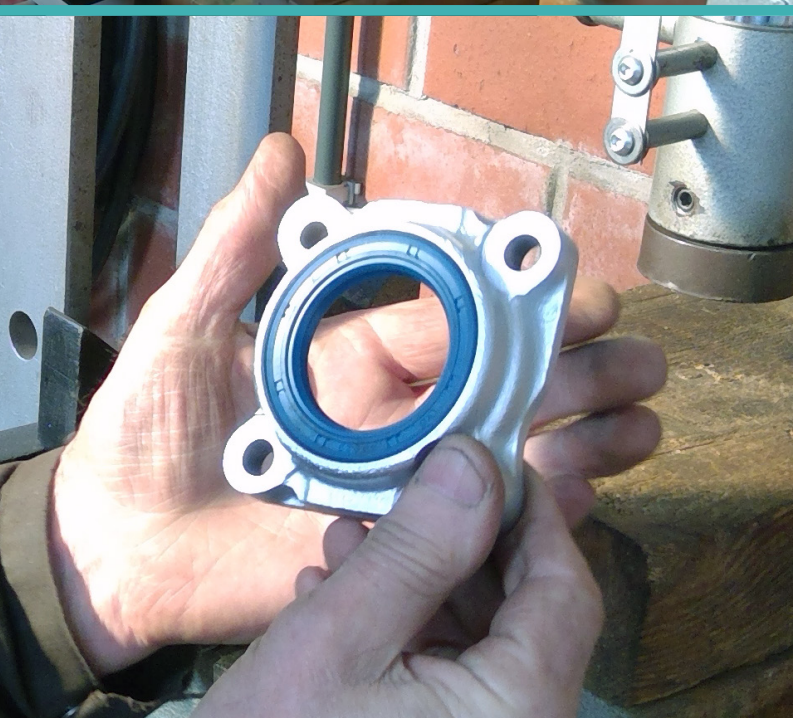


We use a hydraulic press because we have it available, it is ideal for this application. With any technique, it is important that the grease seal is pushed straight in. Check very carefully that the seal slides in evenly on all sides.

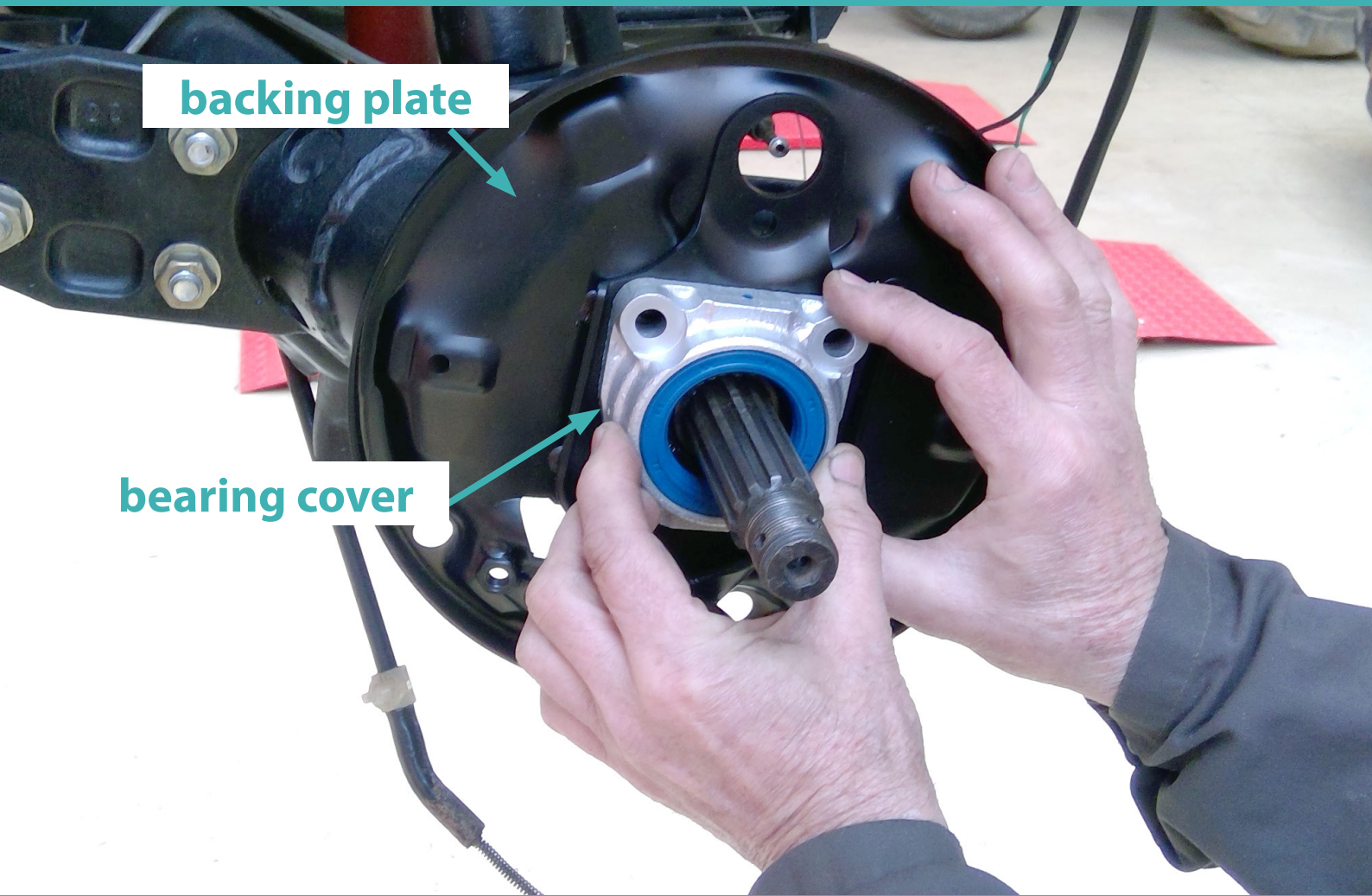


**oil drain**

*For the IRS, the retaining ring is mounted on the outside (photo left), lip inward. With the swing axle, the retaining ring is mounted on the inside (photo below), also with lip facing inward.*







Install the backing plate, making sure the surface to which the backing plate is attached is clean, flat and free of rust.

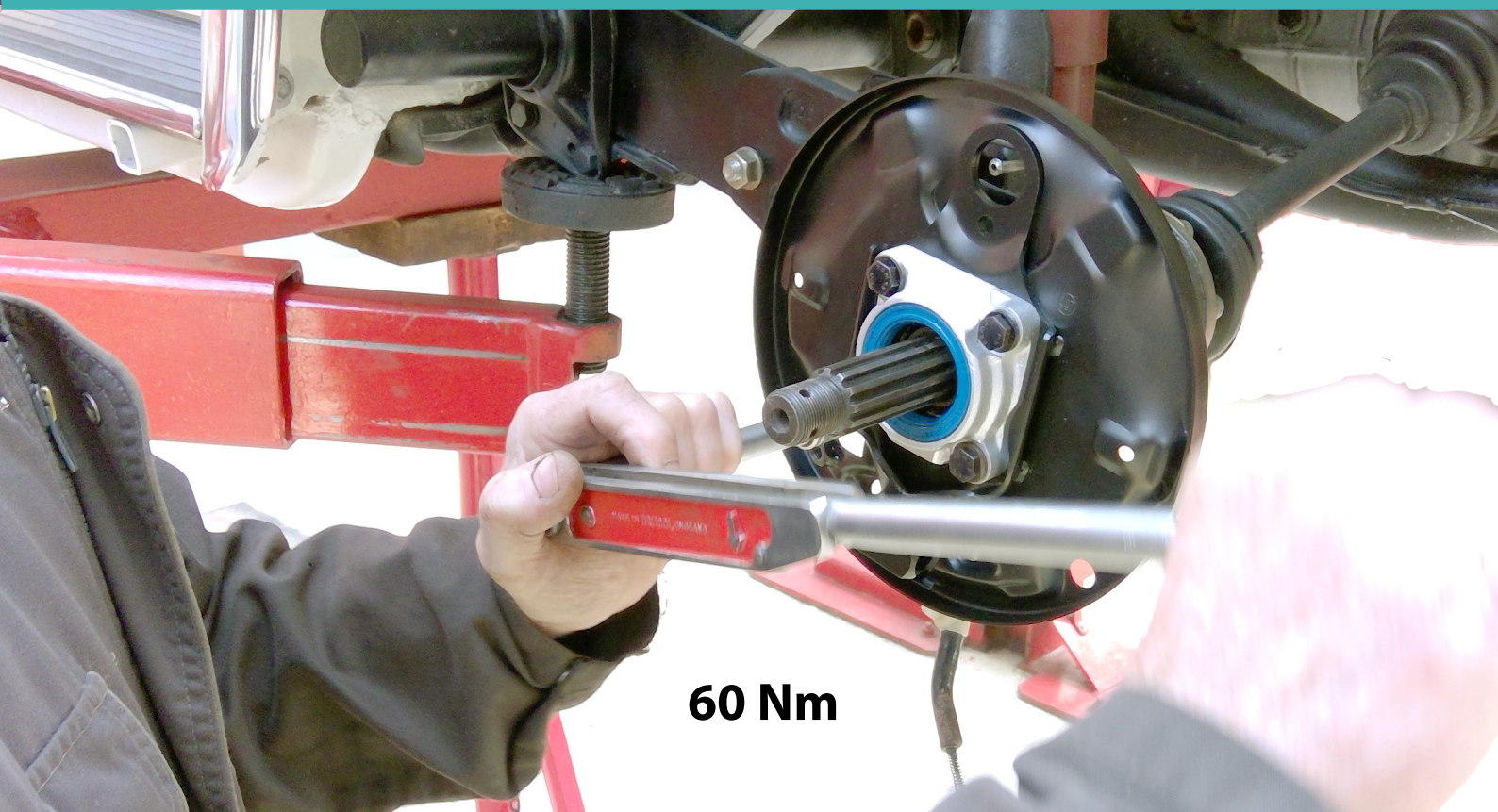
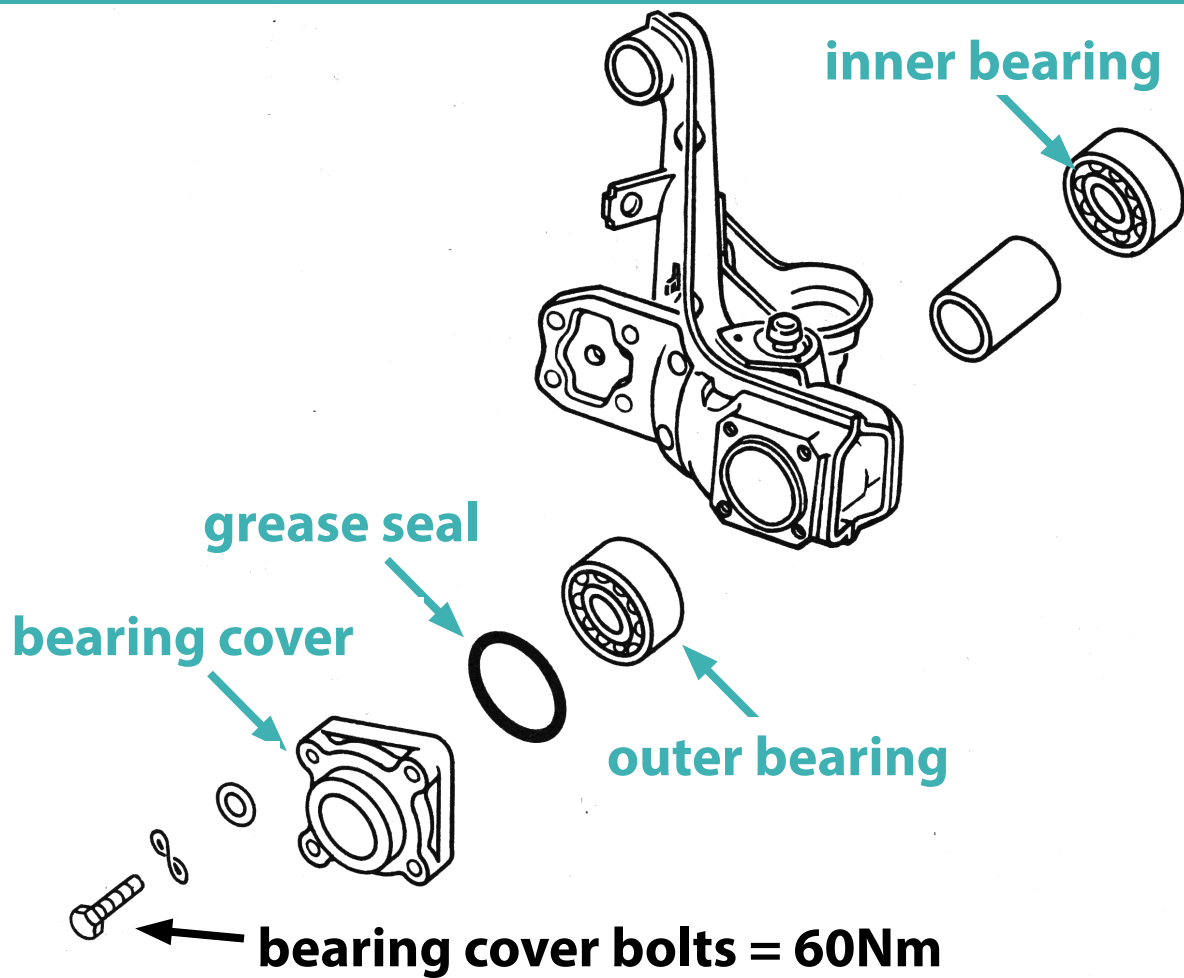
**Caution!** For the bearing cover of a model with swing axle. The drainage hole must be directed towards the bottom (see photos page 7). This hole allows the gearbox oil to drain without contaminating the brake components if the oil seal leaks.

The bearing cover can be mounted (picture above) by means of four bolts, each with a washer and a spring washer. The bolts are tightened with 6 mkg or 60 Nm by using a torque wrench. We show on the sketch on the next page the parts.

We are now ready to assemble the brake parts.



# rear brake assembly



## Installing brake parts

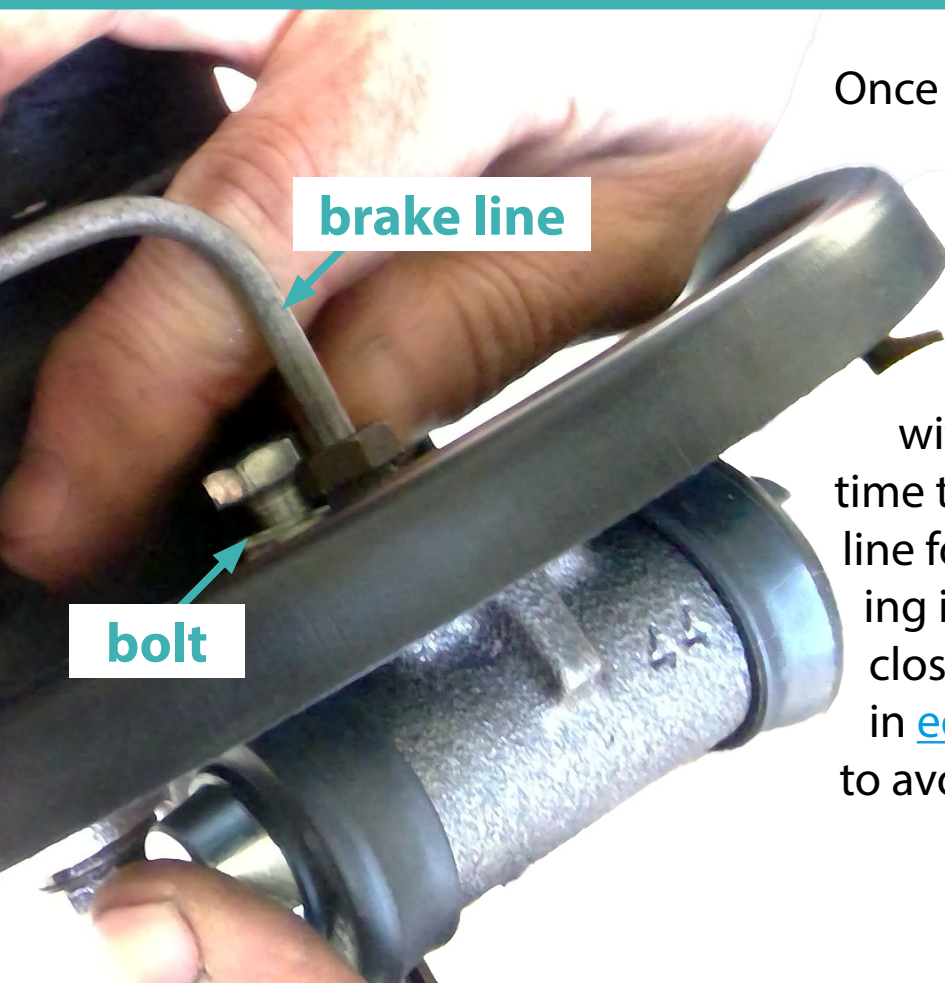
### *Wheel brake cylinder*

The assembly of the brake parts runs quite similarly to that of the front brakes. We discussed the front brakes in [edition 22](#). We start with mounting the wheel brake cylinder. In edition 22 we showed how to prepare a wheel brake cylinder for the front brakes for assembly. It is no different with the rear brakes. The wheel brake cylinders must be treated against corrosion. Read [edition 22 starting on page 39](#) to learn how to prepare the brake cylinders for installation.





# rear brake assembly



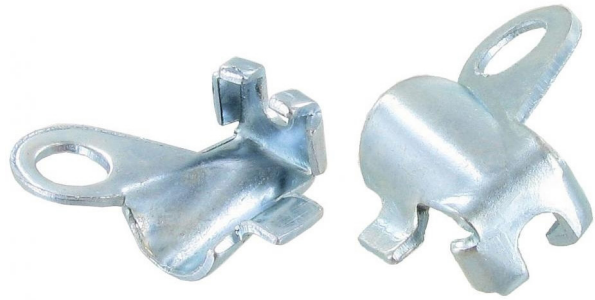
Once the wheel brake cylinder has been treated with the special paste, it can be mounted on the brake backing plate. It is attached to the rear of this VW 1303 with one bolt. It is also a good time to connect the metal brake line for the brake fluid. Tightening is best done with a partially closed 11 mm wrench as shown in [edition 23 on page 28](#), this is to avoid damaging the nut.



### Handbrake cable

This part of the assembly is different from the front brakes. The handbrake lever between the two front seats operates a cable that attaches to the brake backing plate. Its attachment is different for each model, but the principle remains the same.

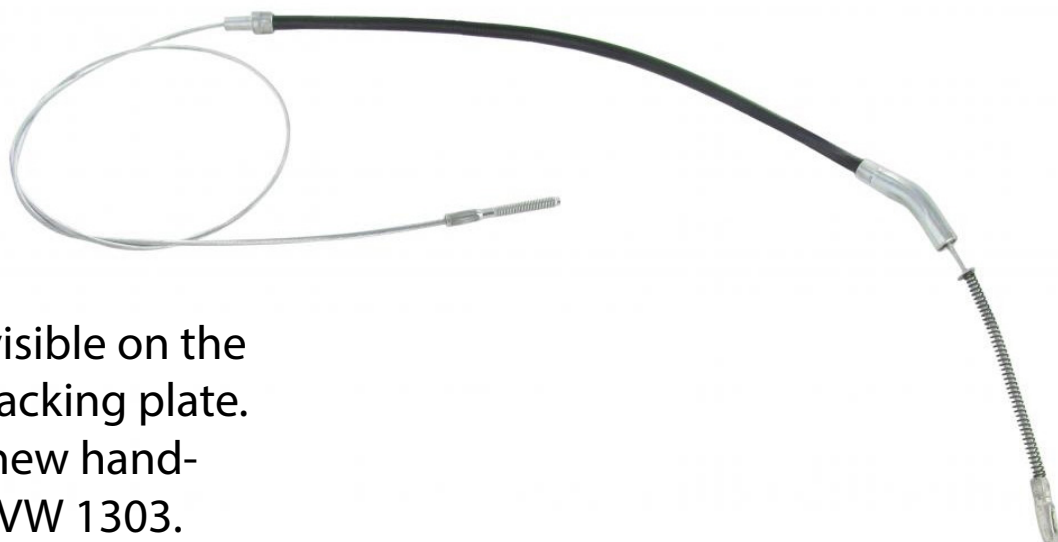
The handbrake cable is slid through the brake backing plate and attached with a special clamp (pictures below).





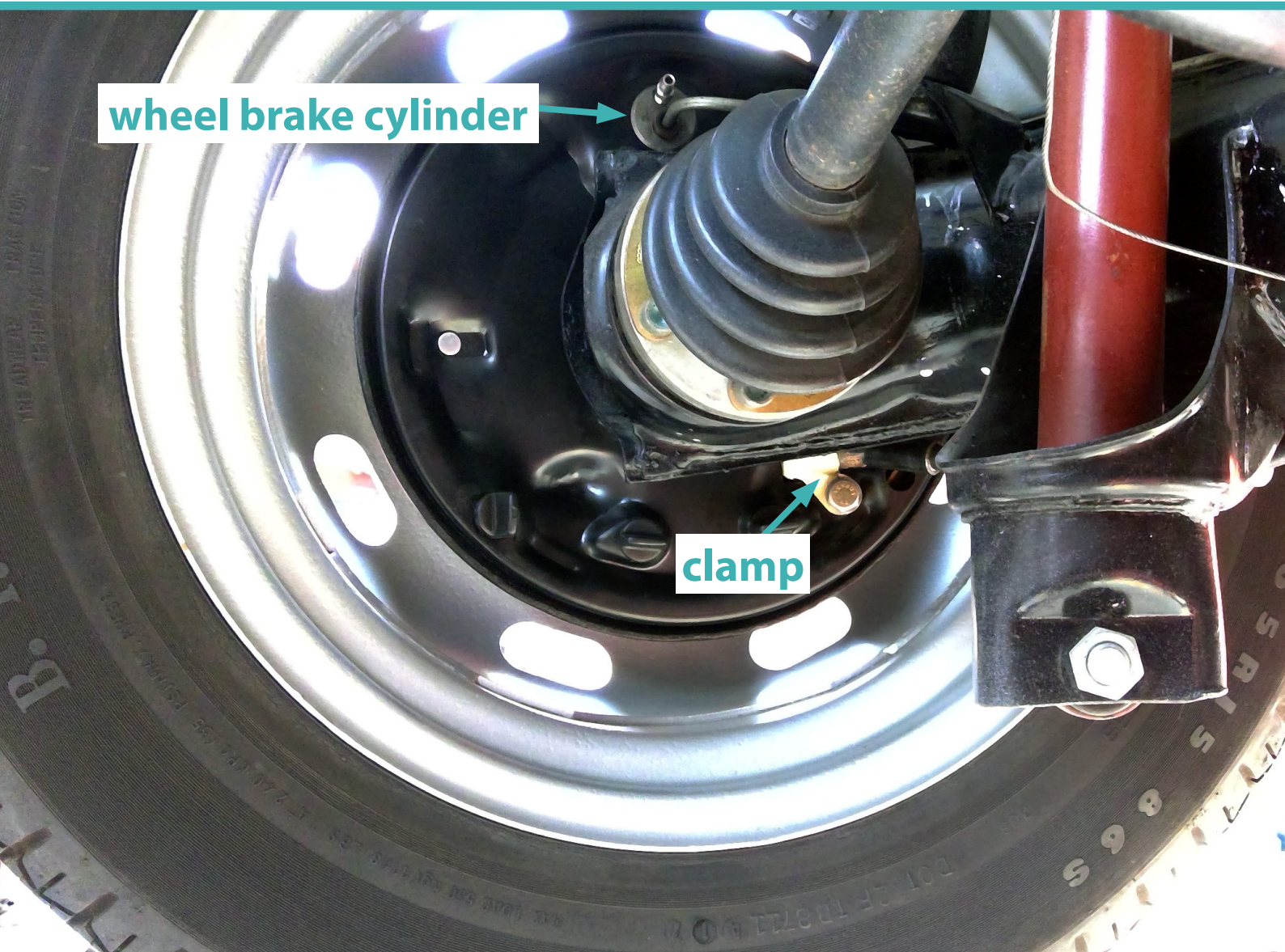
# rear brake assembly

In the photo below, the hand-brake cable with clamp and wheel brake cylinder are visible on the back of the brake backing plate. On the right is the new hand-brake cable for our VW 1303.



**wheel brake cylinder**

**clamp**

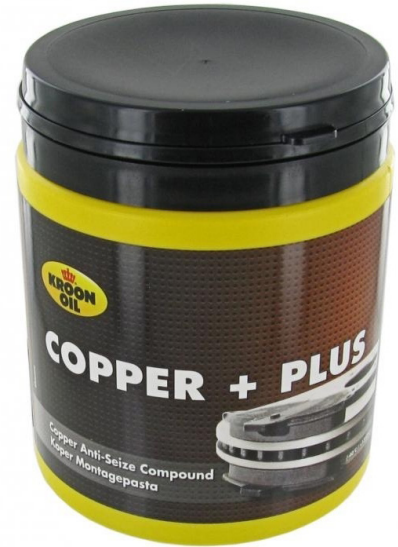




### Adjustment bolts

Installing the rear brake adjustment bolts is similar to the front brakes. We discussed this in detail in [edition 22](#). Use copper grease with caution (photo 11, really not much so as not to contaminate the brake shoes) on the moving parts to avoid squeaking and seizing due to corrosion.

11

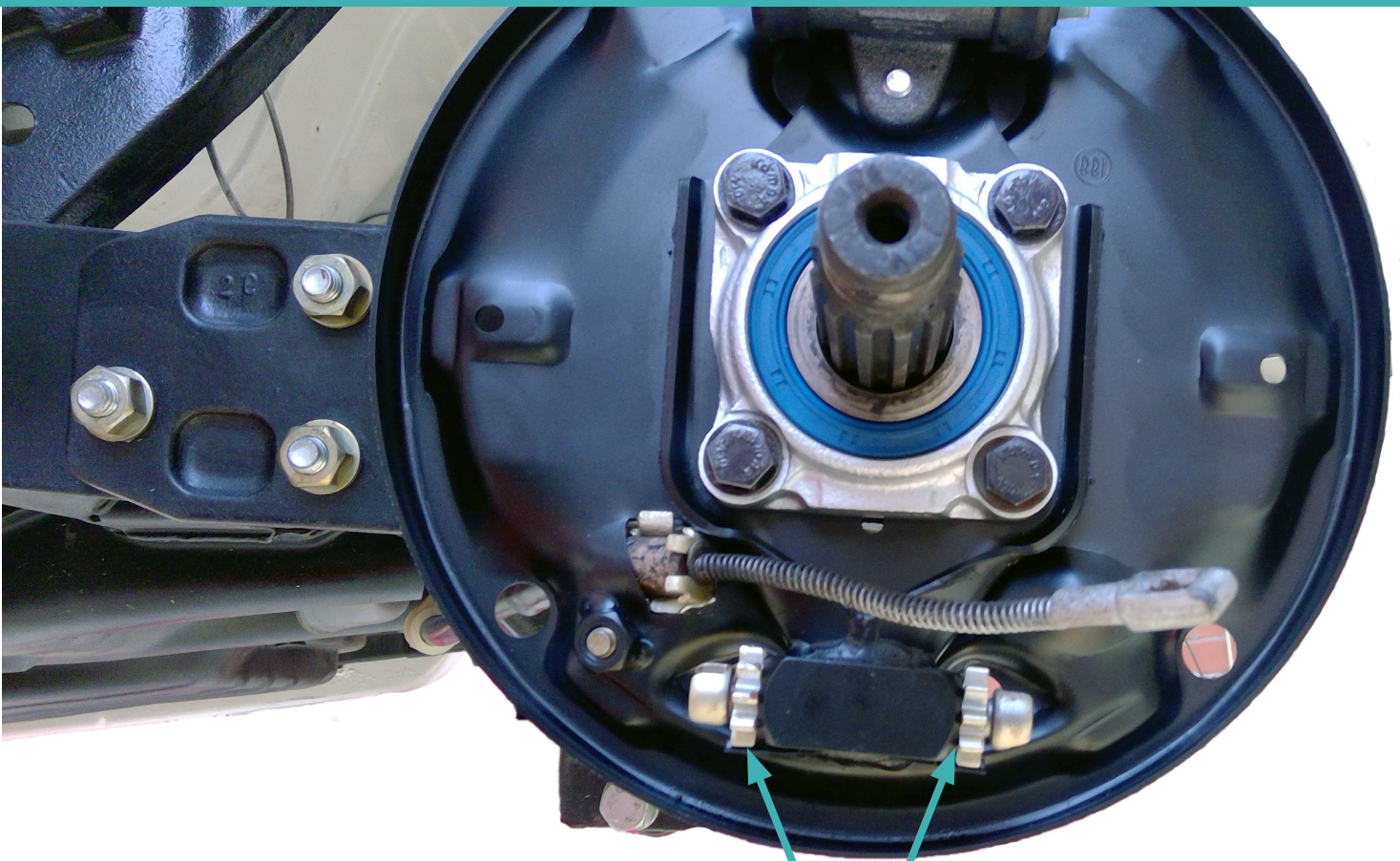


The brake shoes contain metal particles that are released during braking and will stick to the brake parts. The copper grease will protect the adjustment bolts from corrosion.



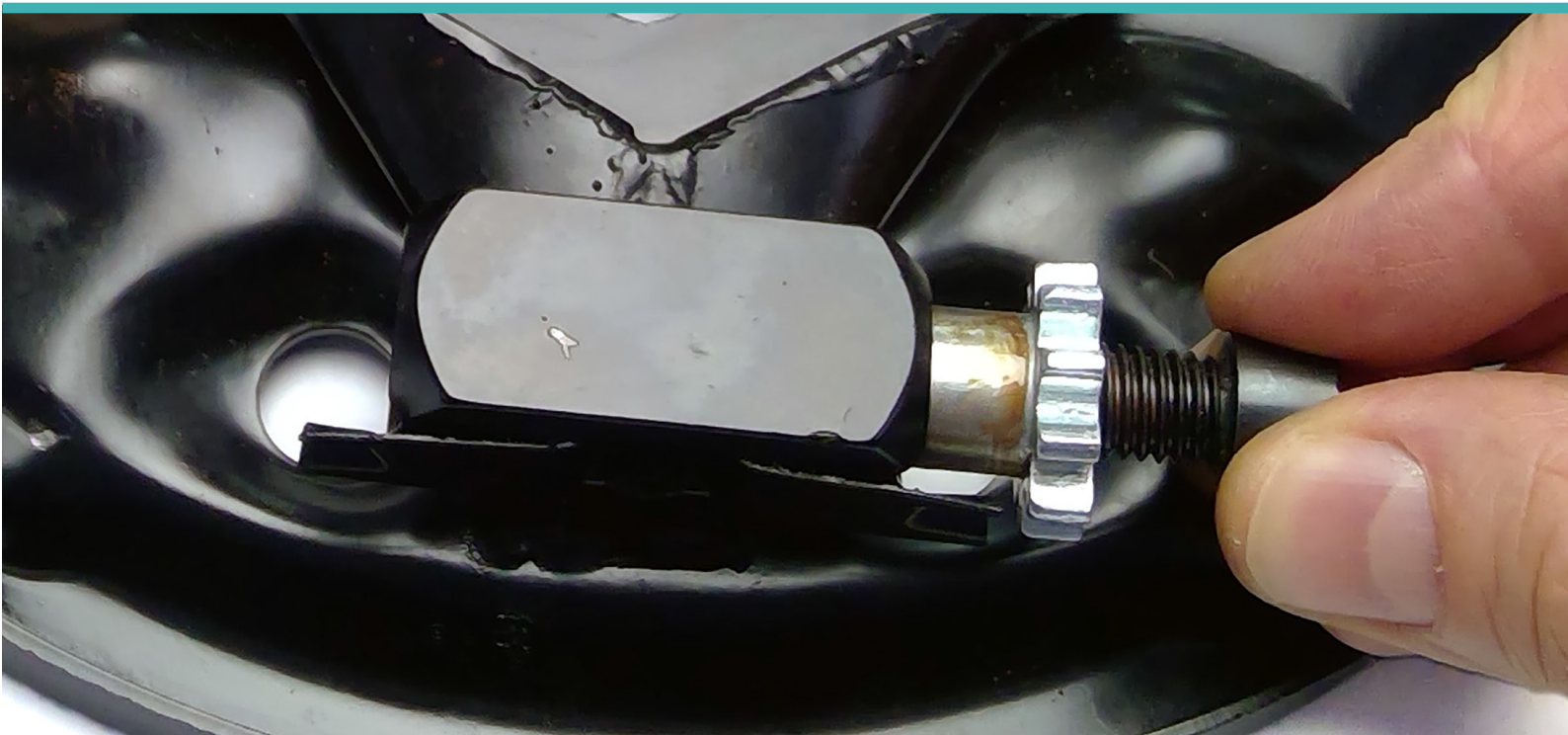


# rear brake assembly



Refer to [edition 22](#) for detailed explanations on how to install the adjustment bolts.

**adjustment bolts**

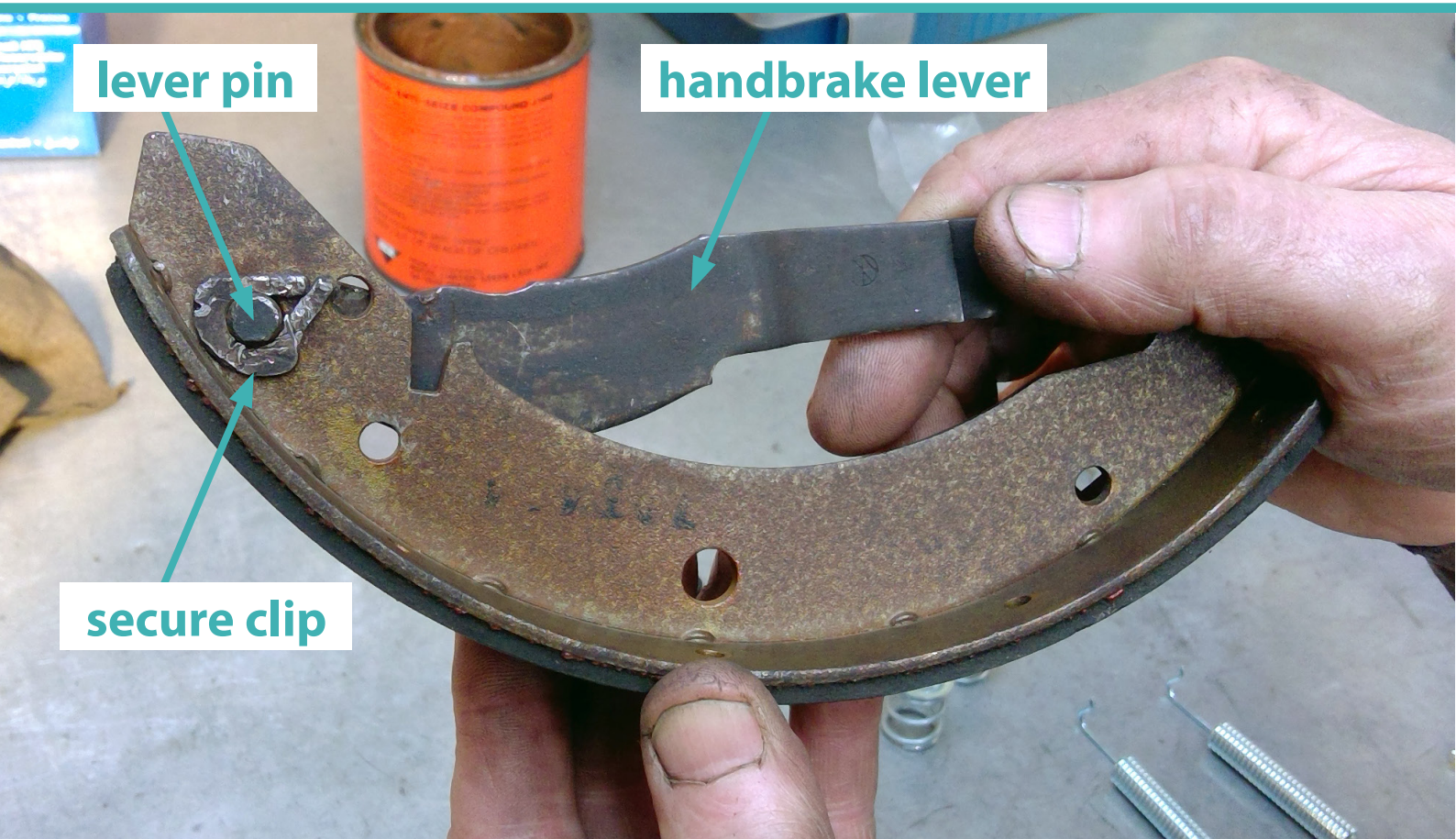




### Brake shoes

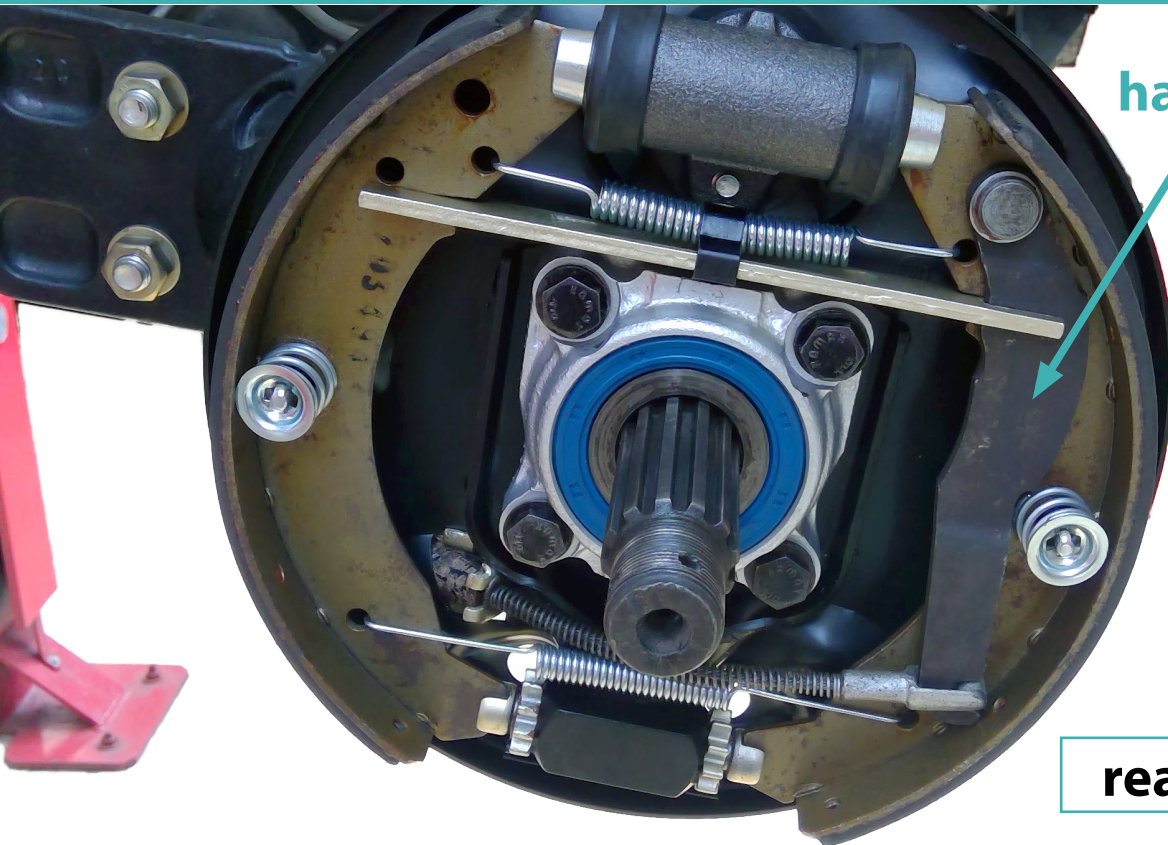
As of now, the mounting of the rear brake parts is different than for the front brakes, and this is because of the handbrake. The handbrake is operated by the handbrake cable (see page 12), this cable in turn operates the handbrake lever. We show on the next page again the intended final result as well as a picture of the front brake for comparison. The difference between front and rear are the handbrake cable, the handbrake lever and the push bar.

The photo below shows a brake shoe we removed from our VW 1303. The retaining clip (or secure clip) was clearly mistreated in the past. We use a new handbrake lever pin with secure clip to attach the handbrake lever to the brake shoe. These are very inexpensive parts, it really doesn't pay to save on them.



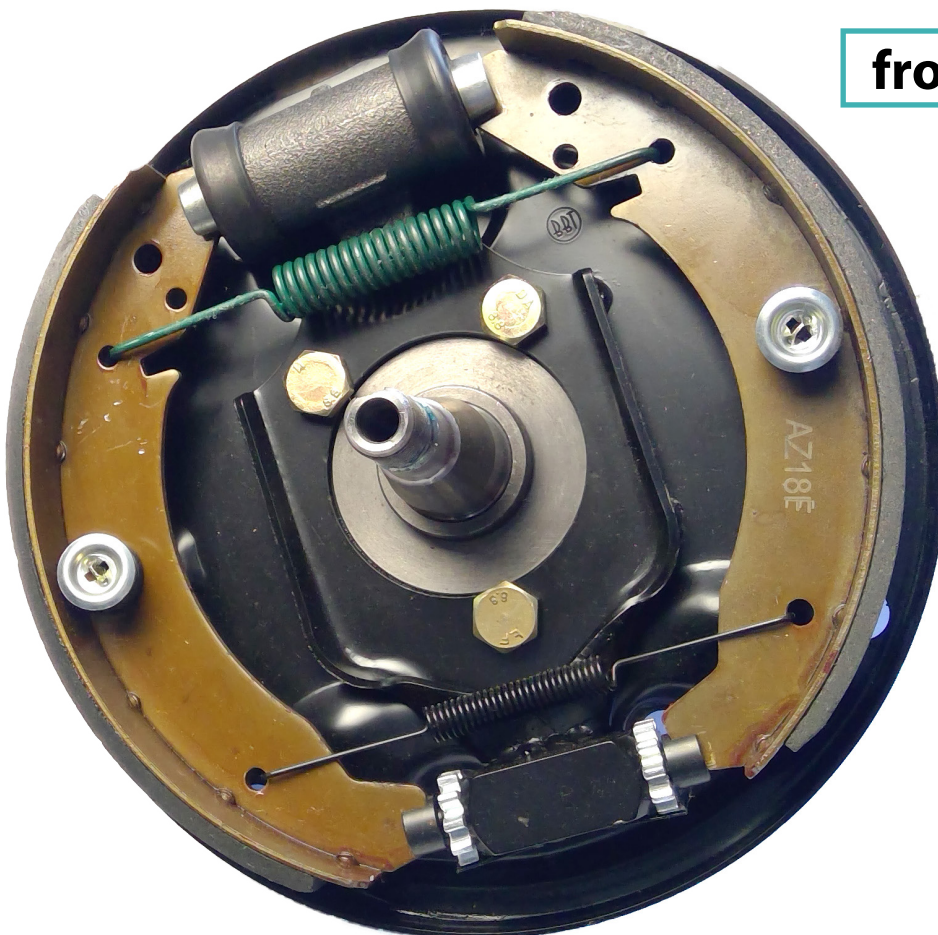


# rear brake assembly



handbrake lever

rear brake



front brake



Again, use a little copper grease on the shaft of the lever pin, and push it through the handbrake lever and through the brake shoe. Use a new secure clip, secure the clip using, for example, a pair of gripping pliers. Check that the handbrake lever moves freely, without resistance and without creaking or squeaking.

lever pin

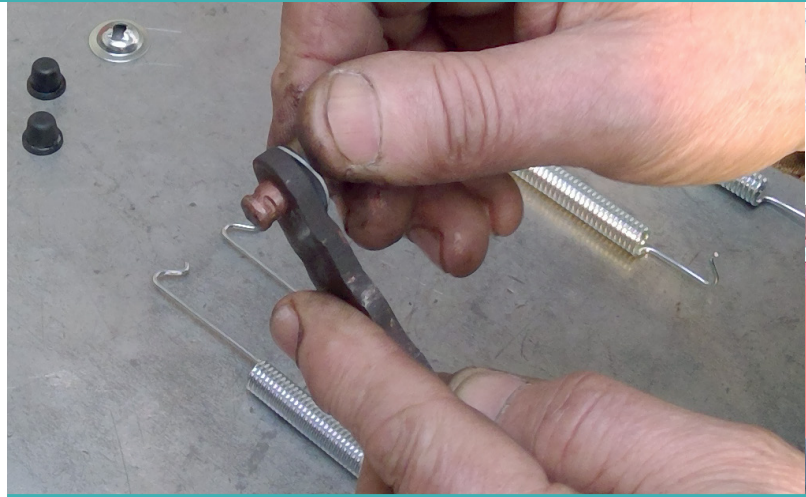


secure clip



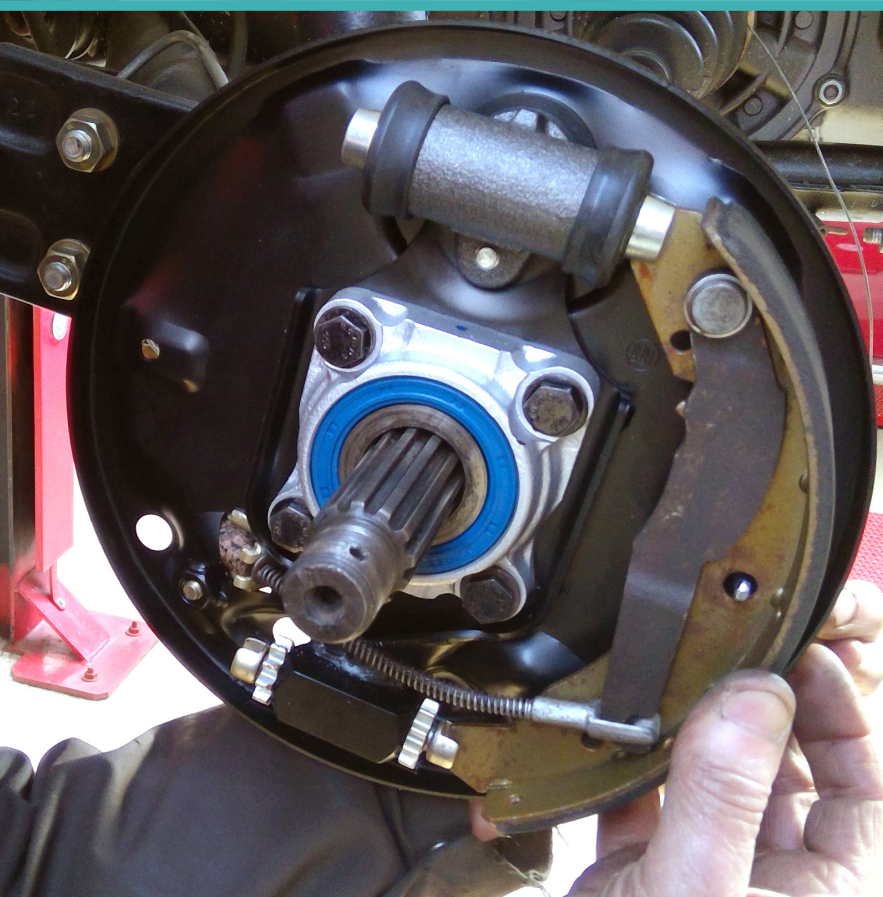
handbrake lever

*Keep the surface of the brake shoe pressing against the brake drum (the brake lining) free of grease or oil. Once contaminated with grease, the brake lining loses its function as a friction material.*



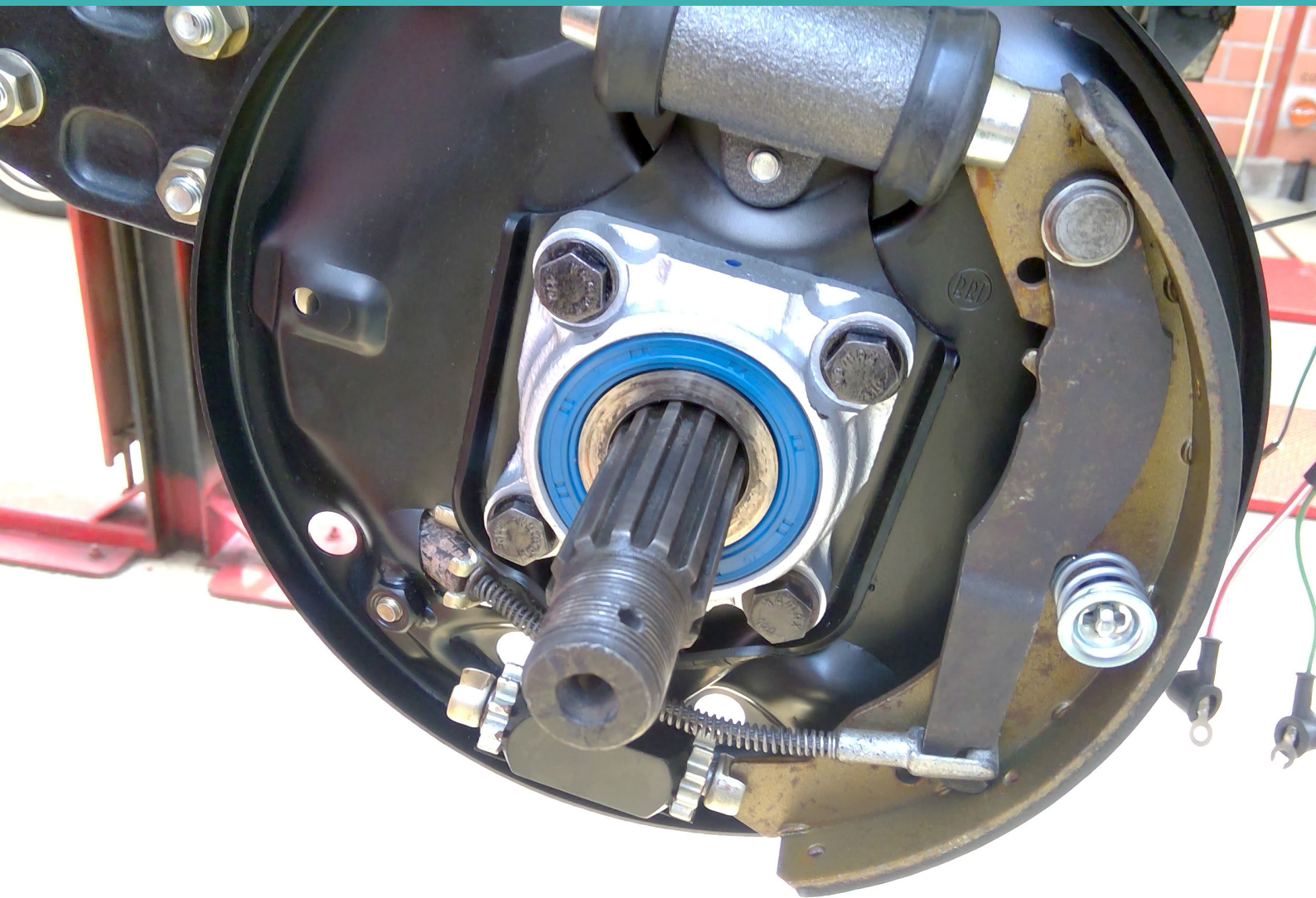


# rear brake assembly

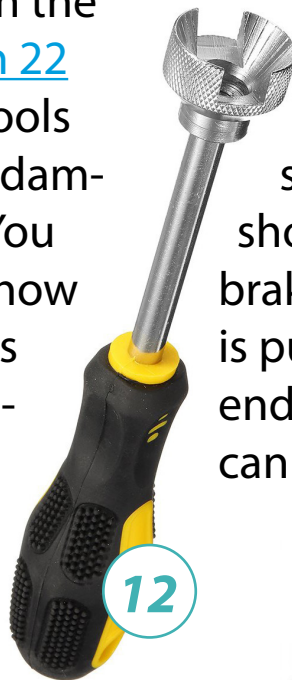


Attach the handbrake cable to the handbrake lever as shown in the photo above. Then place the brake shoe on the backing plate (photo left). Pay close attention to the correct mounting of the brake shoes (each side has a different angle) and the adjustment bolts. You can refer to the explanation in [edition 22 on page 45](#).





Secure the brake shoe with the retaining spring. In [edition 22](#) we have shown the best tools to use for this so as not to damage anything (photo 12). You can also use pliers as we show on page 21, which requires some dexterity and experience. In the picture above you see the brake shoe with handbrake lever ready for use.

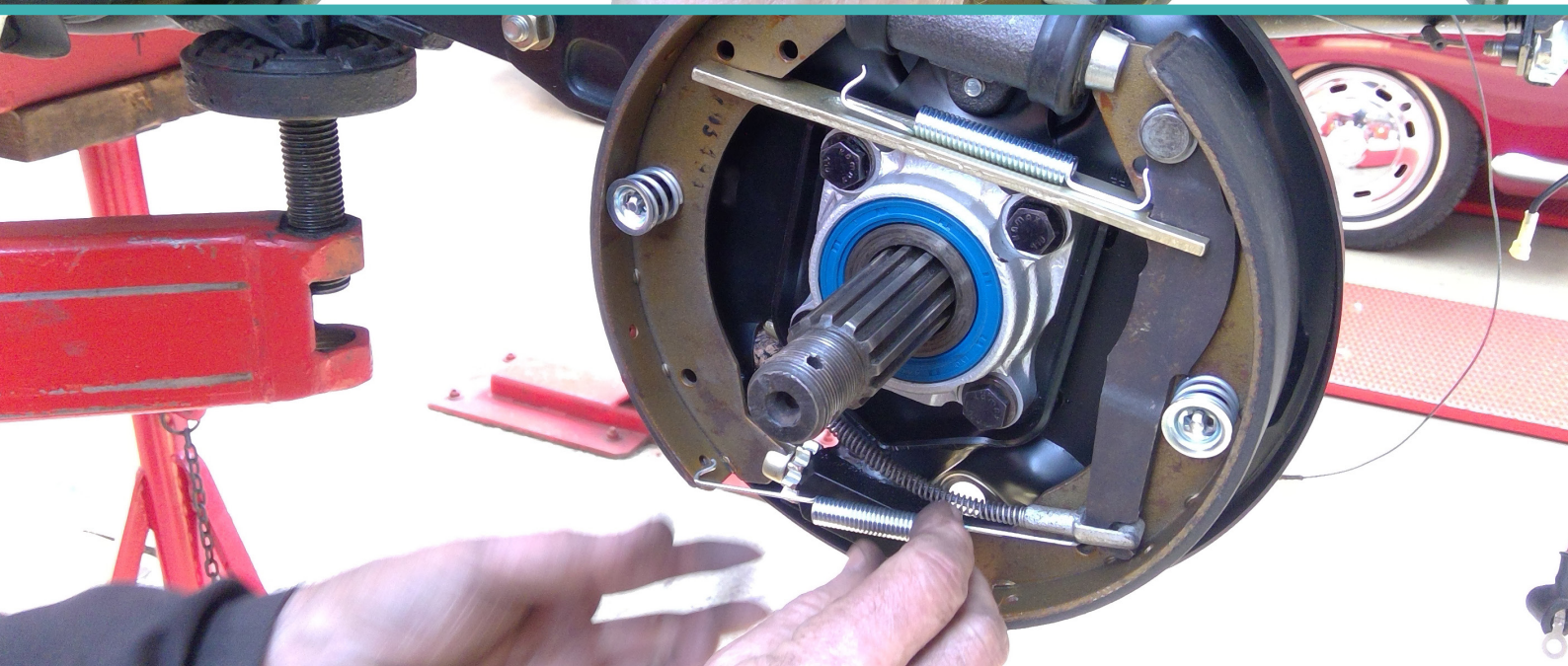
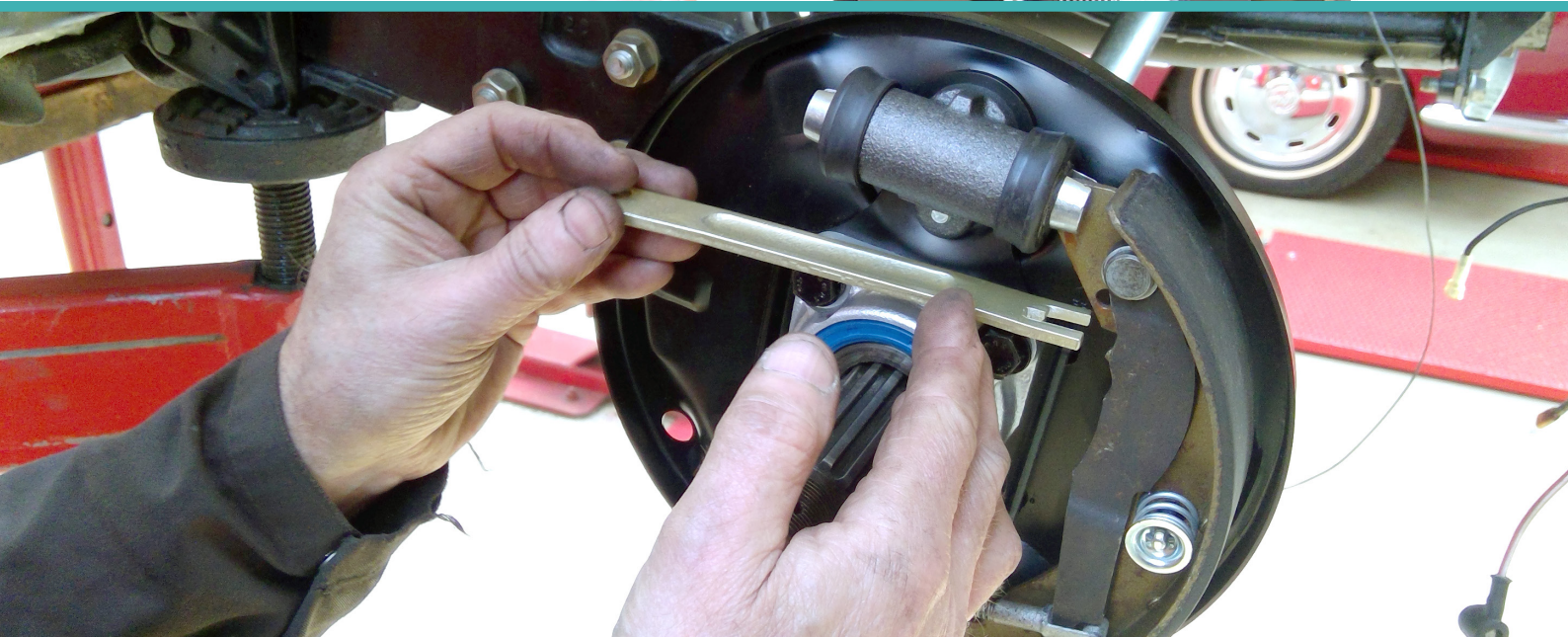
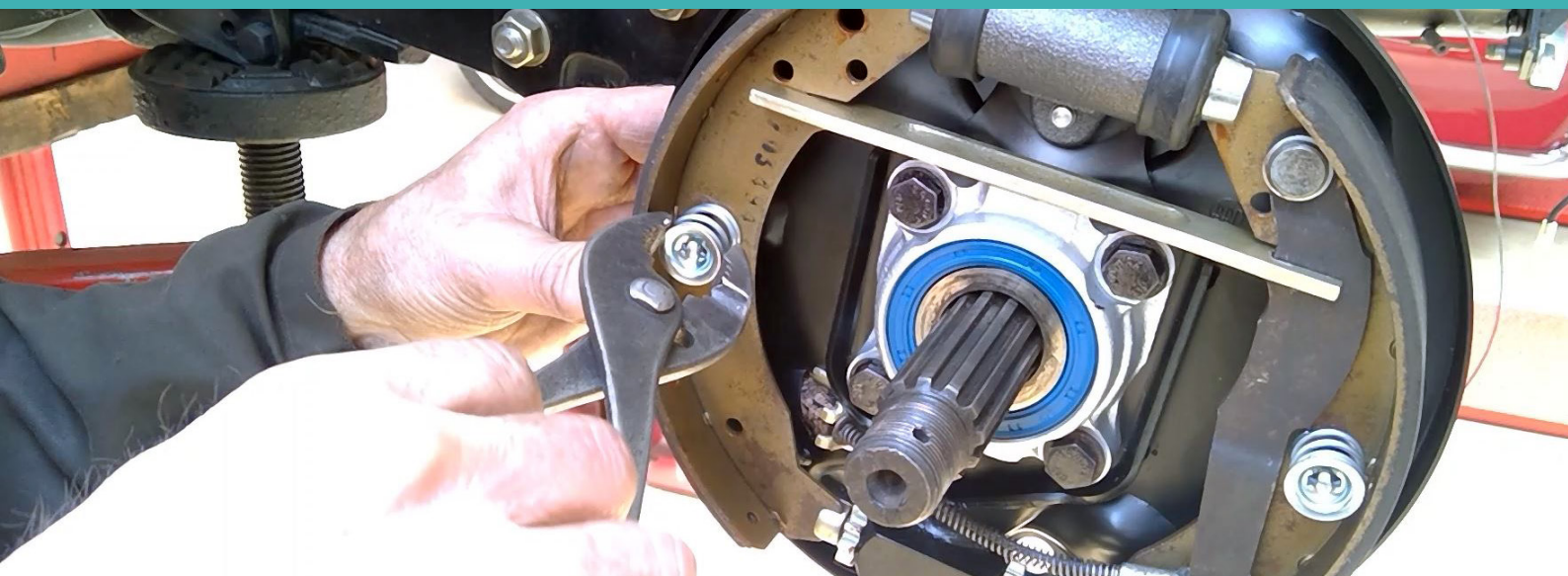


Now the other brake shoe still needs to be mounted with the push rod that serves to move both brake shoes evenly when the handbrake lever between the seat is pulled. The push bar has two ends that are different, as you can see in photo 13.





# rear brake assembly





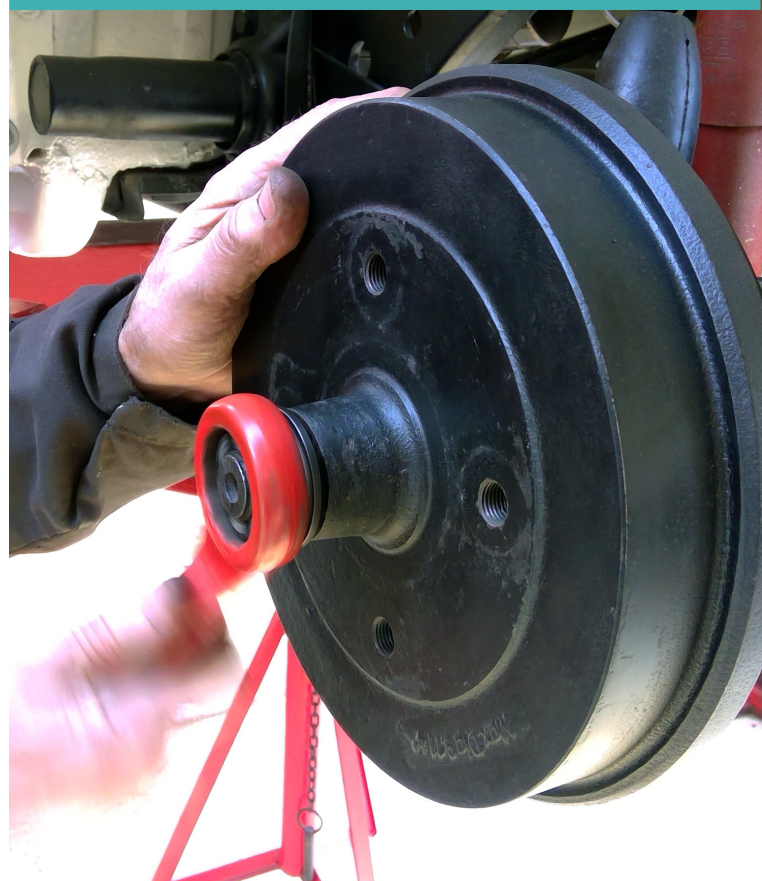
### Brake drum

The brake drum may now finally be mounted. The 36 mm crown nut (photo 14, 46 mm nut for VW Buses after July 1963) of our IRS Beetle used to fasten the drum has to be tightened to 300 Nm (300-350 Nm for swing axle), that's a lot of force. It will not work when the car is not on the ground. You will have to mount the wheel and lower the car to make use of the weight of the car to apply force to the nut (photo below). A torque wrench with a range of 300 Nm is required for this operation.

14



36 mm



300 Nm





# rear brake assembly



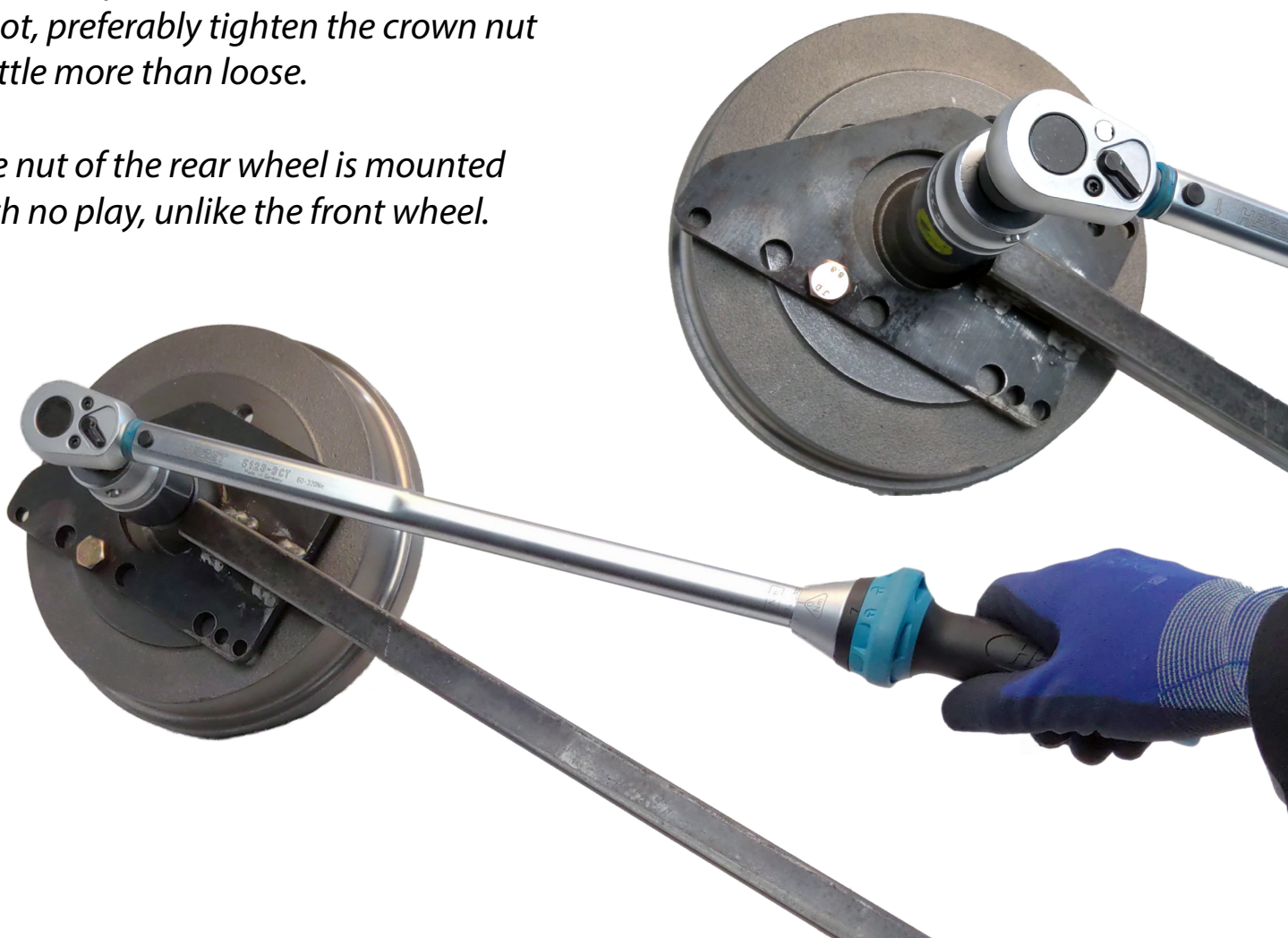
15

A handy tool available in our web store is this force bar (photo 15 and below) that allows you to secure the brake drum without mounting the wheel and thus with the car on the jack or garage lift. This allows you to apply maximum force to the 36 mm crown nut.

*Make sure the crown nut ends in a position such that you can later place the cotter pin to secure the crown nut. If not, preferably tighten the crown nut a little more than loose.*

*The nut of the rear wheel is mounted with no play, unlike the front wheel.*

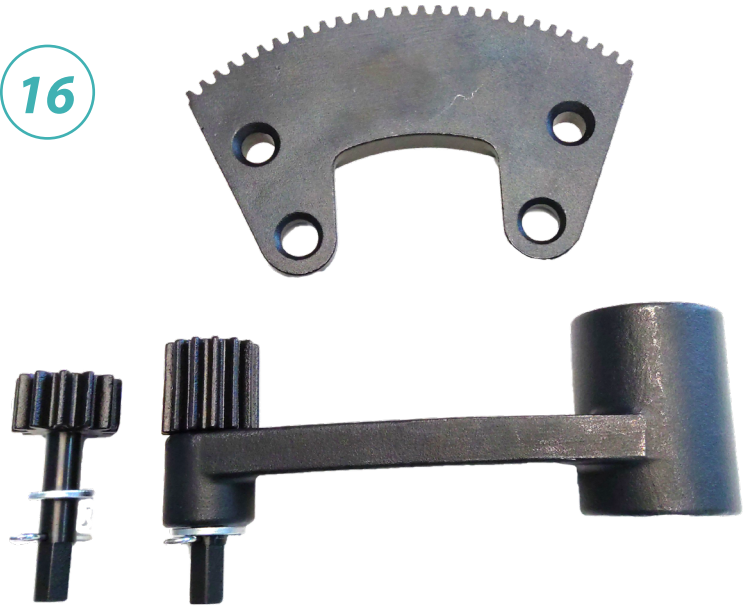
We recommend to use this tool only in combination with a decent garage jack or a lifting platform, not with the VW scissor jack supplied as standard. Attach the tool as shown in the pictures, and set the torque wrench to 300 Nm (for IRS). You can now apply force to the crown nut without the drum spinning.



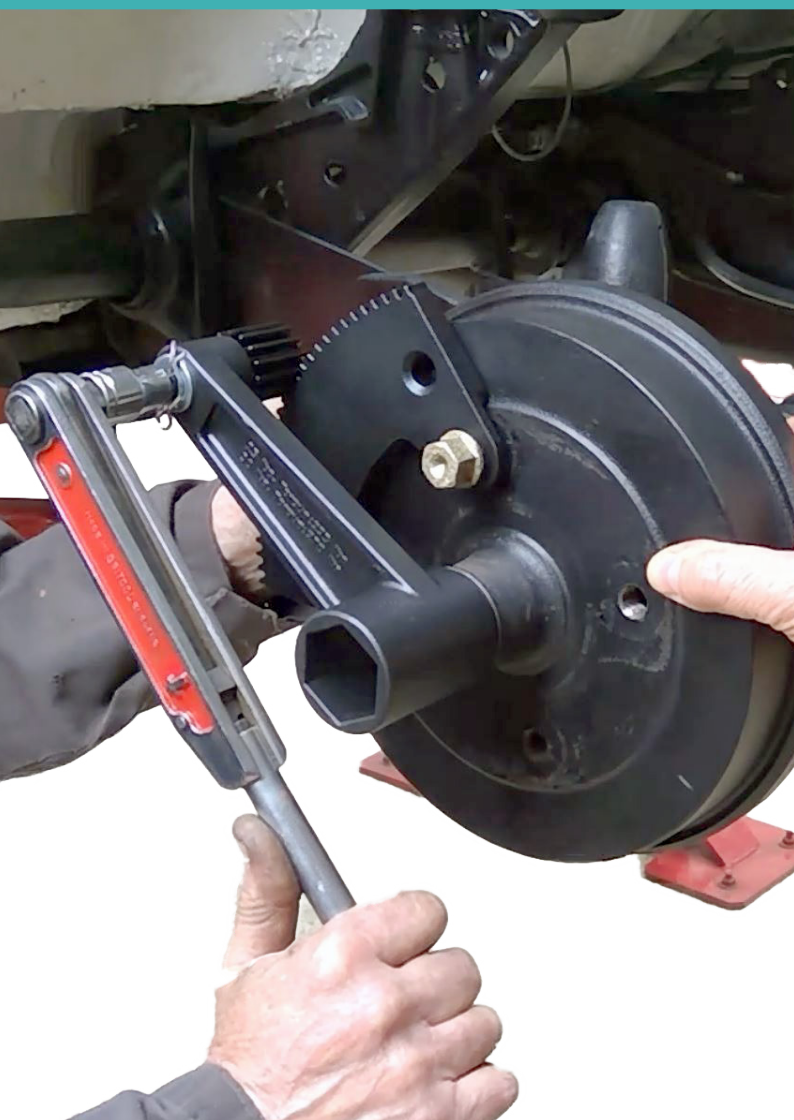


An even more convenient and secure tool is this Torquemeister (photo 16). We refer to [edition 13](#) where we used this same tool to tighten the flywheel. Below we show the Torquemeister in action, you can rest your VW on a lifting platform or garage jack while you tighten the 36 mm crown nut.

16



*The complete set from Torquemeister, including additional gear for the old type flywheel (109 teeth). This tool is provided for 4- and 5-hole rims.*



To tighten the wheel nut, we use Torquemeister's additional tool that attaches to the brake drum with two wheel bolts. To reach 300 Nm we need to adjust the torque wrench to 33 Nm, as the Torquemeister offers a ratio of 9. With a small force of 33 Nm we achieve the same effect than with 300 Nm.





# rear brake assembly

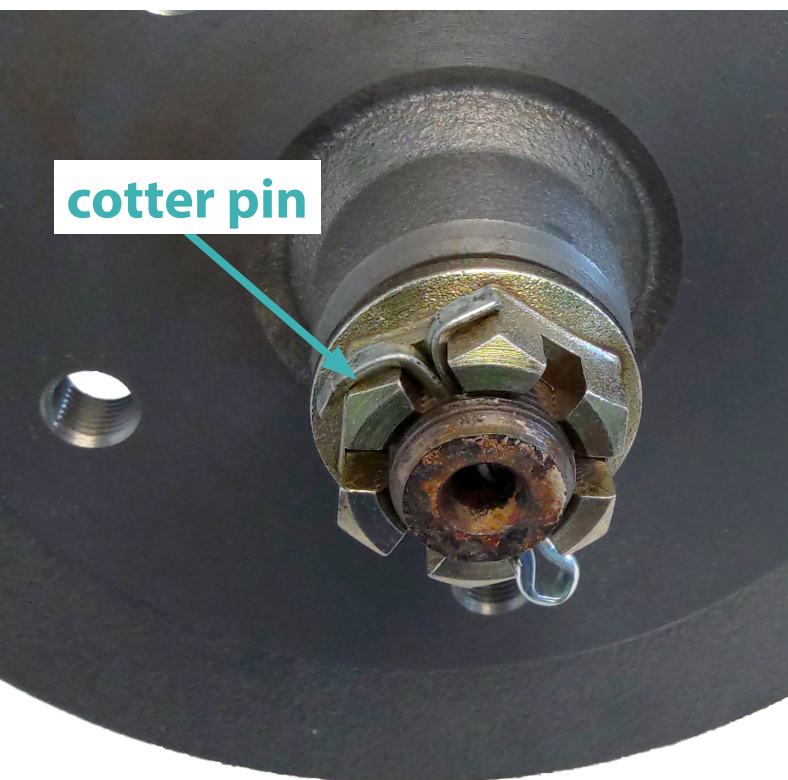


cotter pin

Finally secure the crown nut with a new cotter pin (photo 17). Reusing the old cotter pin is not good practice. Every time the brake drum is removed, it is necessary to renew the cotter pin. The cotter pin secures the crown nut so it can never come loose.

Using a rubber mallet, tap the head of the cotter pin firmly against the crown nut, then bend the longest part of the cotter pin and tap both parts against the crown nut. If the crown nuts are tightened to 300 Nm and the cotter pins are properly secured, the drums are securely attached to the stub axles.

17



cotter pin

## Conclusion

In a subsequent article, we will bleed the brakes and adjust the front brakes, rear brakes and handbrake.



## Introduction

In the previous edition we studied voltage drops. These will occur when, for example, the contacts of a switch are corroded or when the spring tension of a switch or fuse holder is no longer as it was when it came from the factory. The older your Volkswagen the more likely it is that the electrical devices are no longer getting the full 6 volts or 12 volts due to voltage losses between the battery and the actual device.

The smaller the electrical resistance of the device, the more it will consume but the more it will depend on voltage losses across the cables. As most of us have already experienced, the starter motor, the wiper motor and the headlights are the first victims of an electrical circuit that has voltage drops.

In theory, the electrical connections between the devices should offer no resistance, and therefore no voltage losses. We all know that this is usually not the case with an oldtimer. Checking all contacts for corrosion or bad connections is therefore very important.

Connection cables are not always given attention. A cable itself has an electrical resistance that depends on the **diameter** of the cable, its **length** and the **material** used. And of course, a lot can go wrong with that. Old cables will deteriorate, the insulation material will harden and break, connections will come loose. Most VWs have a (mostly unknown) history of 50 years.





# define cable diameter



While repairing or replacing electrical cables, it is important to consult the VW workshop manual to know which diameter cable goes with which branch of the wiring harness. When you start adding accessories, determining the correct cable diameter yourself is extremely important. That is what we will do in this article, calculate yourself what diameter a cable should have. Determining which fuse goes with it, we will do in a subsequent article.

*In the Paruzzi webstore you will find new wiring harnesses for every type of Volkswagen. In some cases you will need to modify or add cables. It is then very important that you can calculate the required cable diameter yourself.*

Previous owners have replaced cables, extended them, they have added electrical consumers (radio/CD, fog lights, extra heating, ...) without thinking about the consequences for the electrical circuit.

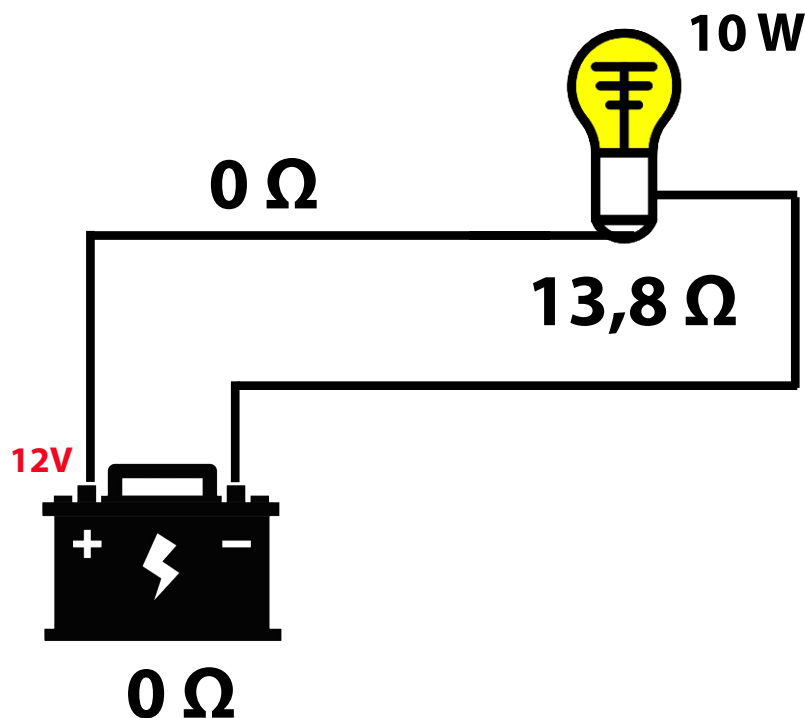
If you are not a fan of calculations, and mathematics was not your favorite subject, then maybe it will seem interesting now, or not. If you only want to read about the practical side, go straight to [page 38](#).



## Cable resistance

Ideally, a cable has a resistance zero, only in this case it will not generate a voltage drop. An ideal world does not exist, unfortunately, we know that an electrical conductor will have a certain resistance. If that resistance is many times smaller than that of the electrical consumer, negligible therefore, then all is fine.

In the previous issue we already showed this simple setup below of a 12 V battery with a 10 W light bulb. A healthy battery has an internal resistance of 0 ohms. If it doesn't, the battery will have a voltage drop, draw power and get hot, and no longer deliver the 12 V necessary for the light bulb. Ideally, the electrical cable will also have a resistance of 0 ohms.



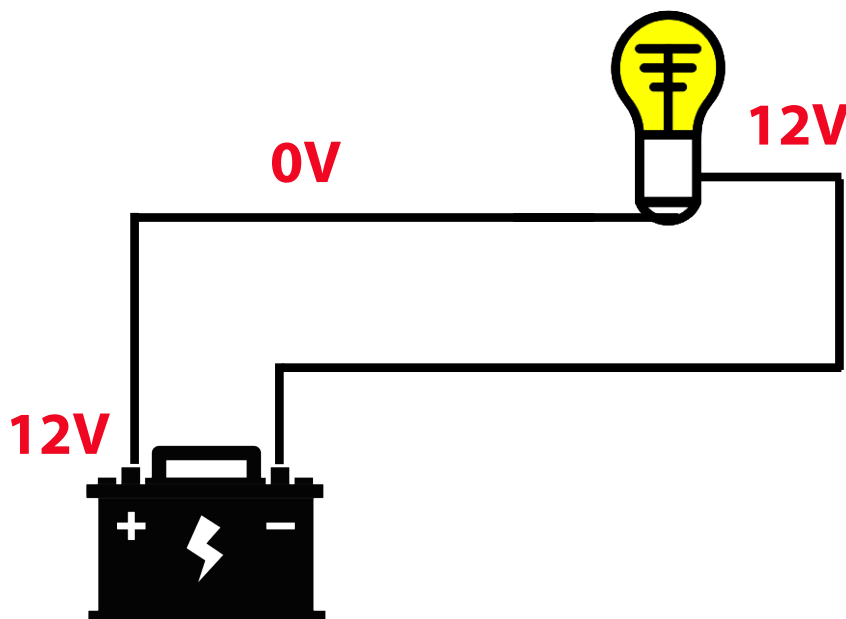


# define cable diameter

If not, then the cable will claim power from the battery, absorb power, get hot, the light bulb will not get full power.

But, in practice, a conductor with resistance zero is not achievable, not in a car anyway. There are solutions to bring the resistance of a conductor to zero (low temperature, superconductors, ...) but they are not feasible in a car, and not really needed.

If the resistance of the electrical conductor is many times smaller than that of the consumer, then the influence will become negligible. So we should aim for an electrical conductor with a resistance many times smaller than the resistance of the consumer. The drawing below shows an ideal world in which the consumer will receive the full power of the battery. We will see later how it works out in practice.





How is the resistance of a cable calculated? The following formula (this is Pouillet's formula) shows that the resistance of a cable will increase as the **length** (L) of the cable increases and as the **cross-sectional area** (A) of the cable decreases, as follows:

$$R = \rho \times L / A$$

Now let's see what this formula tells us.

### **L: cable length**

The formula says that the resistance of the cable becomes zero when the length (L) is zero:

$$R = \rho \times 0 / A = 0 \Omega$$

Or more practically, when the cable is very short. So you should always try to make the **shortest possible connection** from voltage source (battery) to consumer. Extra lengths of cable are out of the question, every additional centimeter of cable will create an additional resistance, and thus a loss of voltage for the device.

The longer the cable, the more resistance it will add. That sounds plausible. Twice as long means twice as much resistance. I know it is tempting to make the cable a little longer than necessary, but the formula is clear, make the cable as long as necessary to make the connection, not an inch longer.



**length = L**



# define cable diameter

## A: cross-sectional area

In the formula, the cross section is at the bottom of the fraction, so, the larger the cross section (the thicker the cable), the smaller the resistance. The formula says that the resistance becomes zero when the cross section becomes very large:

$$R = \rho \times L / \infty \approx 0 \Omega$$

In practice, this statement means that the cable should be as thick as possible.

Now what is the relationship between cross-sectional area and diameter. The cross section A can be calculated by multiplying the square of the radius by  $\pi$ , as follows:

$$A = \pi \times r^2 = \pi \times r \times r$$

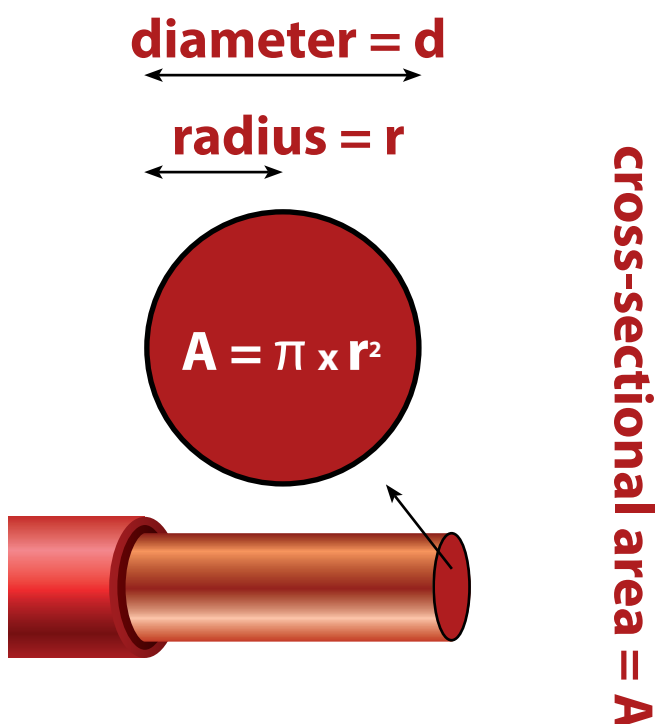
The diameter is two times the radius, so we can write A as:

$$A = \pi \times d/2 \times d/2$$

From this we can derive the diameter as a function of the cross section:

$$d = 2 \times \sqrt{(A / \pi)}$$

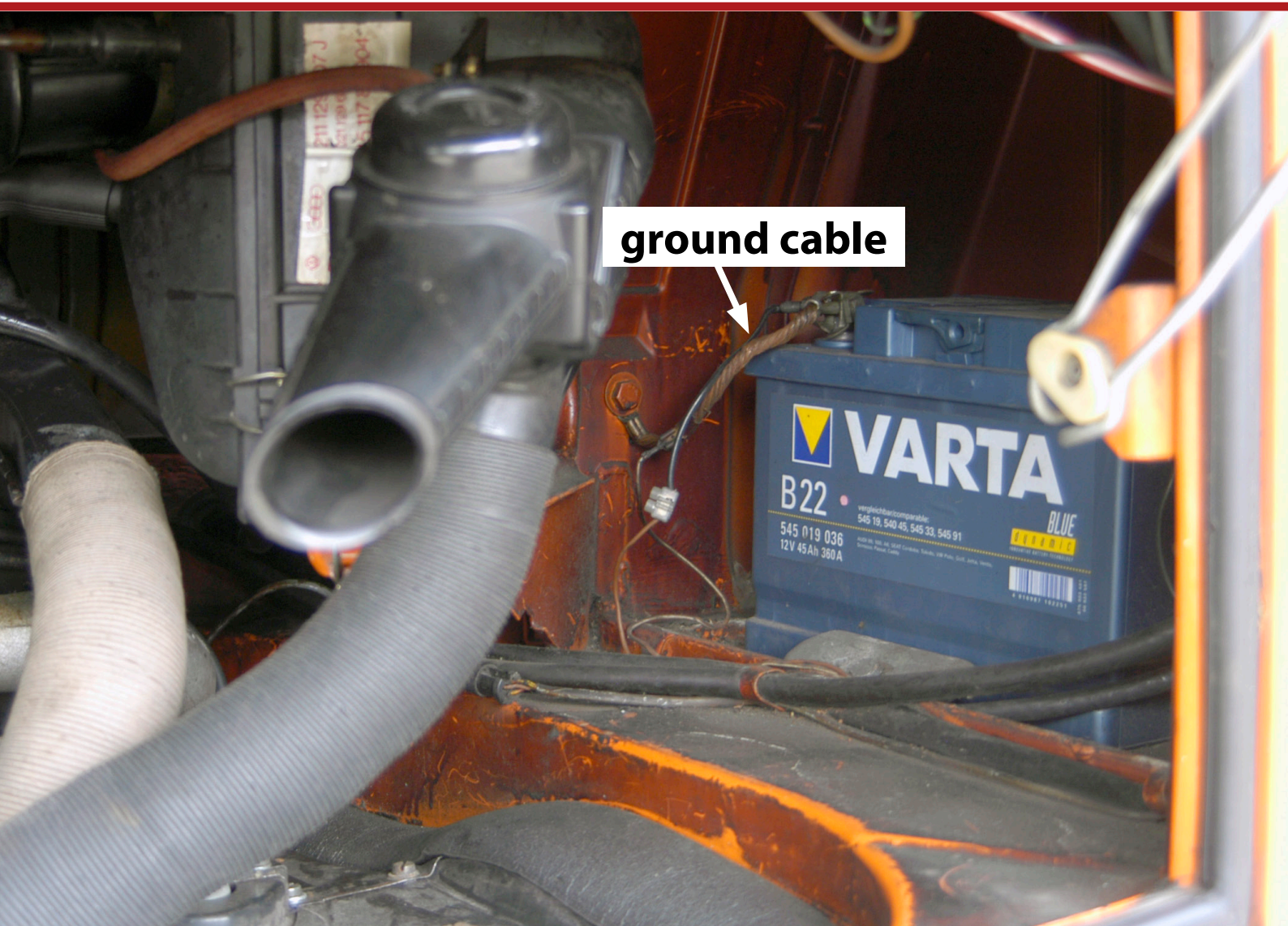
A formula we will soon use to measure the diameter of a cable with a micrometer.





Of course, the cables in your VW should not be too thick either, that would create a problem with the total weight of the car, of course also the cost and there would be a lack of space for the wiring. So the choice is made for cables that can more than bear the current required by the connected consumers.

A practical application of the formula is to use the body and chassis, gearbox and engine crankcase as a ground for the electrical circuit. Instead of making a separate ground cable, which goes to the minus of the battery, for each consumer, most consumers are connected to the chassis (see photo below).



# define cable diameter



**ground cable**

The chassis is a very good, massive electrical conductor, with minimal electrical resistance. The cross-sectional area of the chassis is greater than any other cable, obviously, and it doesn't take any extra weight. Therefore, it is very important that all connections to the chassis or body be very clean. A freshly powder-coated chassis can block electrical flow. So first remove the paint before connecting the ground cables.

The thicker the cable the lower the resistance. That's easy, let's always use the thickest cable we have.

This is unfortunately not possible for car manufacturers, there is a limitation in available space and a limitation in budget. The thicker the cable the more expensive. The objective is to use the most suitable cable, which is still just thick enough not to offer too much resistance.

Remember our previous comment, if a cable offers too much resistance compared to the resistance of the consumer, it will absorb power, get hot, in an extreme case the cable insulation will melt or the conductor itself will burn out. So do not guess the cable diameter, follow the guidelines in this article.

In short, the **shorter** the cable the better, the **thicker** the cable the better. What are the other things to watch out for?



**$\rho$ : Resistivity**

In the formula for cable resistance, you will also see the symbol  **$\rho$** . This stands for the resistivity of a conductor. Each material has a different resistivity, so you want to choose a material for your car's electrical conductors with the lowest possible resistivity, of course the material price and strength also play a role.

You can find the resistivity of various materials in tables, usually given at ambient temperature (20°C). We show in the table the resistivity for a number of good electrical conductors like aluminum, gold, copper, silver and for a number of good electrical insulators like bakelite, porcelain, glass, rubber.

In the automotive industry, copper was chosen because this material is more affordable and resists tensile forces better than the more conductive aluminum.

Material	Resistivity $\rho$ ( $\Omega\text{m}$ )
Aluminum	$2.65 \cdot 10^{-8}$
Gold	$2.2 \cdot 10^{-8}$
Copper	$1.68 \cdot 10^{-8}$
Silver	$1.59 \cdot 10^{-8}$
Bakelite	$10^5$
Porcelain	$10^{12}$
Glass	$10^{12}$
Rubber	$10^{15}$

The resistivity of copper as shown in the table is  $1.68 \cdot 10^{-8}$ . That is the same as: 0.0000000168  $\Omega\text{m}$ .

*If you have trouble converting from mm to m, or with the scientific representation of numbers ( $1.68 \cdot 10^{-8}$ ), take a look online, there are numerous conversion tools that can help you. There are also online calculators to calculate cable resistance.*



# define cable diameter

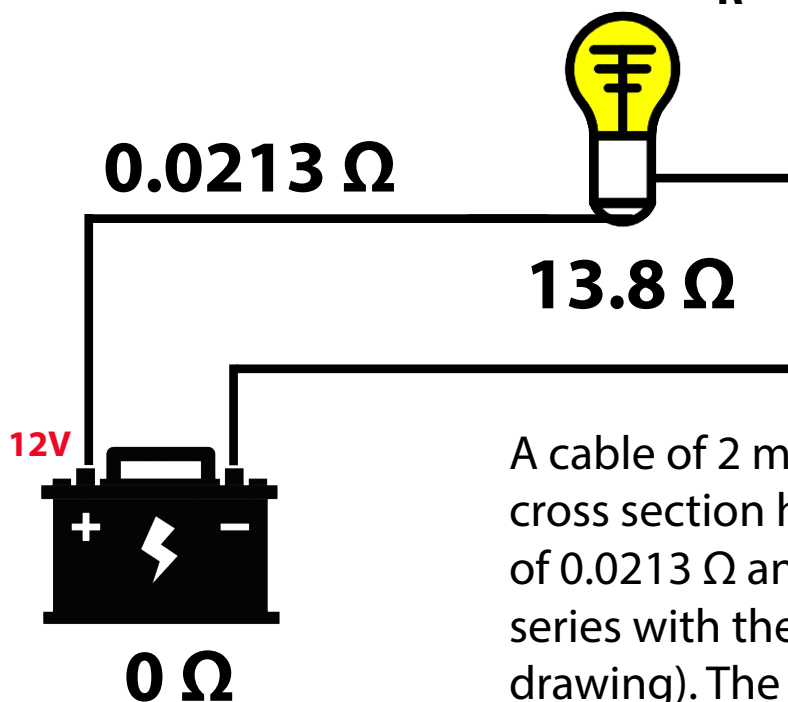
Below is a repeat of Poisson's formula (see page 30):

$$R = \rho \times L / A$$

We can now use the formula to easily calculate the resistance of a cable of our Volkswagen to better estimate what role it will play in the distribution of the voltage.

We take the cable running from the light switch on the dashboard to the rear light (5 W). According to the electrical diagram, this is a copper cable with a cross section of  $1.5 \text{ mm}^2$  (everything must be converted into meters, this is  $0.0000015 \text{ m}^2$  or in scientific mode  $1.5 \cdot 10^{-6}$ ). The length of the cable from the dashboard to the rear light is about 2 meters. So the resistance of the cable is (at  $20^\circ\text{C}$ ):

$$R = 0.0000000168 \times 2 / 0.0000015$$
$$R = 0.0213 \Omega$$



A cable of 2 meters and  $1.5 \text{ mm}^2$  cross section has a resistance of  $0.0213 \Omega$  and is connected in series with the light bulb (see drawing). The light bulb is 13,8 ohms (see [edition 23](#)).



If we perform the calculation again as in the previous edition, the light bulb will have a voltage of:

$$U_{\text{light bulb}} = U_{\text{battery}} \times (R_{\text{light bulb}} / R_{\text{total}})$$

$$U_{\text{light bulb}} = 12\text{V} \times (13.80 \Omega / 13.8213 \Omega)$$

$$U_{\text{light bulb}} = 11.98 \text{ V}$$

The light bulb with a 1.5 mm<sup>2</sup> cable of 2 meters gets almost the full 12 V, namely 11.98 V. If the cable would be 0.5 mm<sup>2</sup> then the resistance is three times greater, the light bulb now gets only 11.94 volts. Every tenth volt will be a visible loss of efficiency of the lighting. This is a known phenomenon with the 6 volts Volkswagen, they have become notorious for weak lighting.

### t: Influence of temperature

But an even more important consequence of the increase in cable resistance is the power the cable will absorb, and the (sometimes disastrous) effects on cable temperature.

A copper cable will always have some resistance, even if it is very small. When an electric current (I) flows through the wire, an amount of power (P) will be consumed:

$$P = U \times I$$

This absorbed power will cause the wire to heat up. An increase in resistance occurs in a copper conductor as the temperature rises. The resistance increase is within certain temperature limits, practically proportional to the temperature increase. The change in resistance value is expressed by  $\alpha$ , which is the temperature coefficient.



# define cable diameter

For copper,  $\alpha$  is 0.0038. If the cable heats up from 20°C to, say, 100°C because, for example, too much current is running through it, because too many consumers are connected, or because the cable is too thin, the resistance of the cable increases as follows:

$$\alpha \times (100^{\circ}\text{C} - 20^{\circ}\text{C})$$

$$0,0038 \times (100^{\circ}\text{C} - 20^{\circ}\text{C}) = 30\%$$

The resistance of our 2-meter, 1.5-mm<sup>2</sup> cable was 0.0213  $\Omega$  and will increase 30% to 0.0277  $\Omega$  due to heating. However, the heating of the wire will increase more than the power. This is because for metals, the  $\rho$  value, and therefore the resistance increases with increasing temperature. With the increase in resistance, more power will be drawn and the wire heats up even more ... the consumer will receive less and less power, the cable heats up more, until the insulation melts or the cable burns out.

Therefore, the amount of current that is allowed to flow through a conductor with cross-sectional area  $A$  is limited. If the upper limit is exceeded, the wire heats up too much so that the insulation melts and the risk of short circuits increases.

It is therefore very important that the electrical conductor remains cool, such that the full power goes to the consumer. To achieve this, you must ensure that the cross-sectional area of the cable is large enough to keep the developed power of the cable low. If we look at the formula  $P = I^2 \times R$  we see that the greater the desired current, i.e. the bigger the electrical consumer, the smaller the resistance of the cable must be to achieve the same power. The smaller the resistance the larger the cross section of the cable.

But how can I determine the cross section?



## Determine cable diameter

Now we come to the practical part of this article, how do you determine how thick an electrical conductor should be? We will explain how to do that practically, even if you did not follow the explanations in the previous pages.

A voltage loss across the electrical conductor is inevitable, we are dealing with copper and we cannot make the cross section of the cable infinitely large.

A total voltage loss of 5% across all contacts and switches is considered acceptable. This leaves 95% for the consumer. If the battery gives 12.5 volts with no-load, this leaves 11.88 volts for the consumer. Of the 5% losses, we will assume that 0.5% comes from the electrical cable and 4.5% from the contacts, fuses, switches ...

0.5% as the maximum voltage drop across the cable is usable for both 12 V and 6 V.

As an example, we will take the addition of 55 W fog lights like the one below. We assume we have exactly 12 V at the plus of the fuse box. We take a cable length of 2 meters from the fuse box to one light. The connection to ground is made through the chassis, so this connection will have minimal resistance (negligible).



# define cable diameter

If we take into account a maximum voltage loss of 0.5% across the conductor then a maximum of 0.06 volts should be lost across this conductor. The current that each light will consume, if 12 volts is connected (minus the loss of 0.06 volts), is:

$$I = P / U$$

$$I = 55 \text{ W} / 11,94 \text{ V} = 4,61 \text{ A}$$

You will have to switch the fog lights with a relay.

We use ohm's law to determine the desired resistance of the cable for a maximum voltage drop of 0.5%:

$$R = U / I$$

$$R = 0,06 \text{ V} / 4,61 \text{ A} = 0,01 \Omega$$

We now know that the cable must have a maximum resistance of 0.01 ohms.

Using Poisson's formula, we can determine the cross section, as follows:

$$A = \rho \times L / R$$

$$A = 0,0000000168 \times 2 / 0,01$$

$$A = 0,0000032 \text{ m}^2$$

Everything so far was in meters, we want to convert everything to mm, because the cross section of cables is expressed in  $\text{mm}^2$ , we need to convert  $\text{m}^2$  to  $\text{mm}^2$ , you do that by multiplying A by 1,000,000.

$$A = 3,2 \text{ mm}^2$$

So the cable for the spotlight must be at least  $3.2 \text{ mm}^2$  if we want to have less than 0.5% voltage loss. We take into account 2 meters of cable because the ground is connected to the chassis (otherwise 2 times 2 meters).



In all these calculations we assume an ambient temperature of 20°C. If cables are bundled together, then covered with plastic isolation or heat shrink tubing and located very close to the engine, the temperature can rise very high. High ambient temperatures (over 45°C in some countries) can also cause high temperatures under the trunk lid. As we saw earlier, a temperature increase from 20°C to 100°C will mean a 30% increase in resistance.

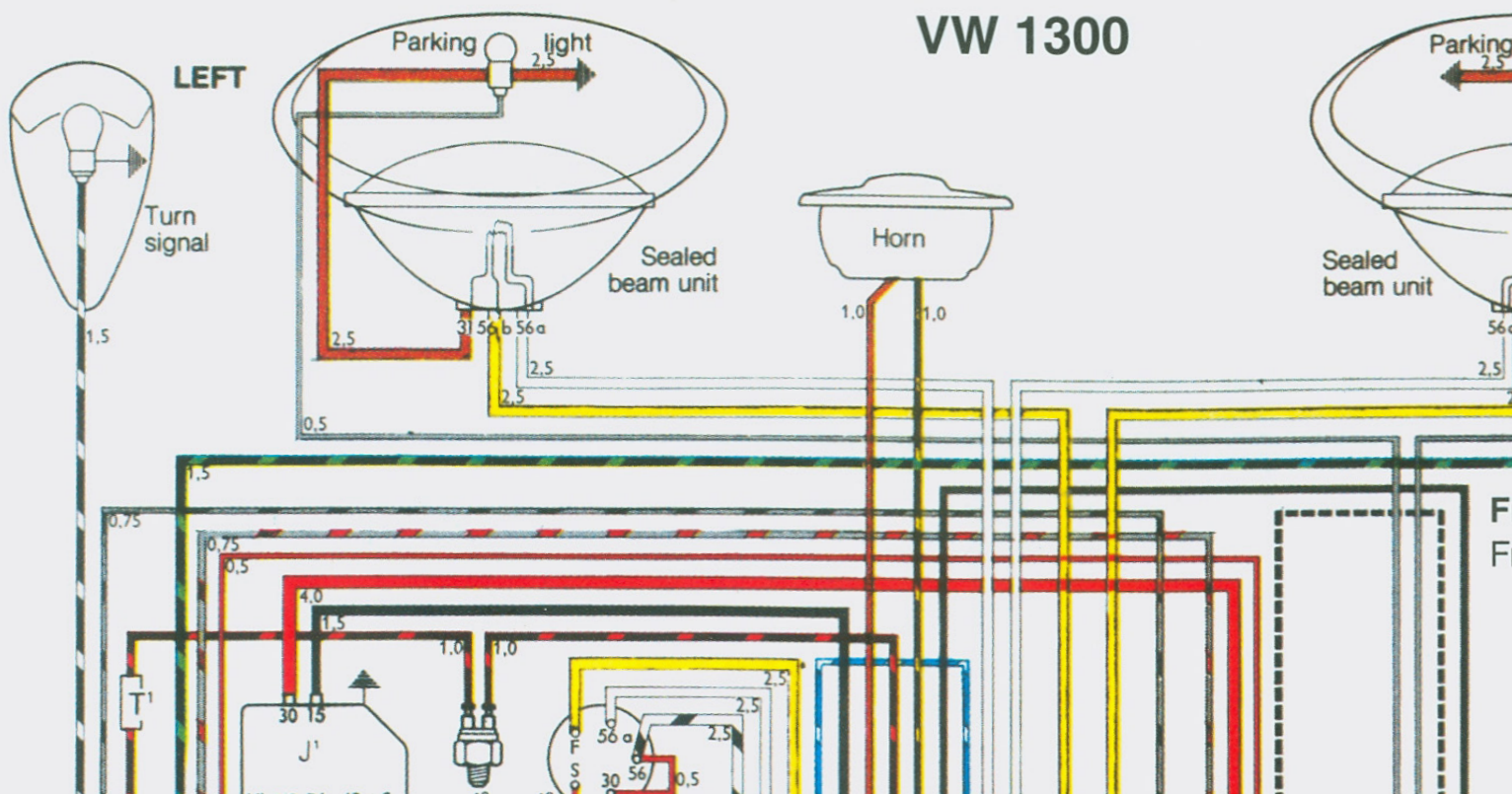
So we have to take a margin to account for heat that our cables are exposed to.

If we look at what cross section Volkswagen used in a VW 1300 (diagram below), it will give us an idea of how far we are from the calculations made by the factory:

**headlight 45 W => 2,5 mm<sup>2</sup>**

**blinker 21 W => 1,5 mm<sup>2</sup>**

**our lights 55 W => 3,2 mm<sup>2</sup>**



# define cable diameter

If the cross section is not mentioned on the cable, you can measure it with a micrometer. Usually a cable is cylindrical, the formula to calculate the diameter (d) as a function of the cross-sectional area is as follows (see page 31). If we use the calculated cross section 3.2 mm<sup>2</sup> from page 39, we can calculate the diameter:

$$d = 2 \times \sqrt{(A / \pi)}$$
$$d = 2 \times \sqrt{(3,2 / 3,14)} = 2,02 \text{ mm}$$

*The thinnest cable encountered in our VW is 0.5 mm<sup>2</sup>. Although thinner could be done, it is not recommended because the cable becomes too fragile.*

If you don't know the diameter of a cable, you can determine it with a micrometer. If your cable is at least 2.02 mm thick, then it would be usable for the spotlights. In practice we take a wire diameter that is available as standard. The picture below shows how we measure a 2.5 mm<sup>2</sup> cable, the diameter is 1.7 mm. Do the math with the formula on the left.

## Conclusion

This article has tried to make it clear that you can't just use any cables, and, try to keep the length as short as possible and calculate the diameter of the cable according to the consumer.

And, of course, these consumers will need a separate fuse. An additional fuse in the original fuse box if there is still room, or a line fuse, read about fuses in [edition 05](#)).





## Introduction



While working on old Volkswagens, it is common to encounter bolts that do not belong to that application for which they are used. Too easy inexperienced enthusiasts will replace a bolt with another bolt they have available. The result may be that the thread in, for example, the body, chassis or ball joint is damaged, which you then notice immediately. Worse is when a bolt breaks after some time due to overloading, you do not want to experience that when it comes to brakes or suspension.

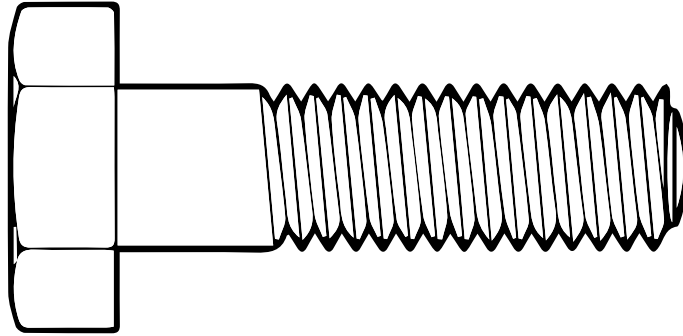
According to Wikipedia, a bolt is a round rod of metal or other material to which threads have been applied and which has a head. When combined with a nut, it is a means of connecting two or more objects. When the head has a slot, a cross, an Allen ... then one speaks of a screw.

The primary purpose of this article is to make the reader aware that bolts exist in various designs. It is certainly not the intention to list all types of bolts, but rather to indicate the most important properties to take into account.



# metric bolts

## Bolt properties

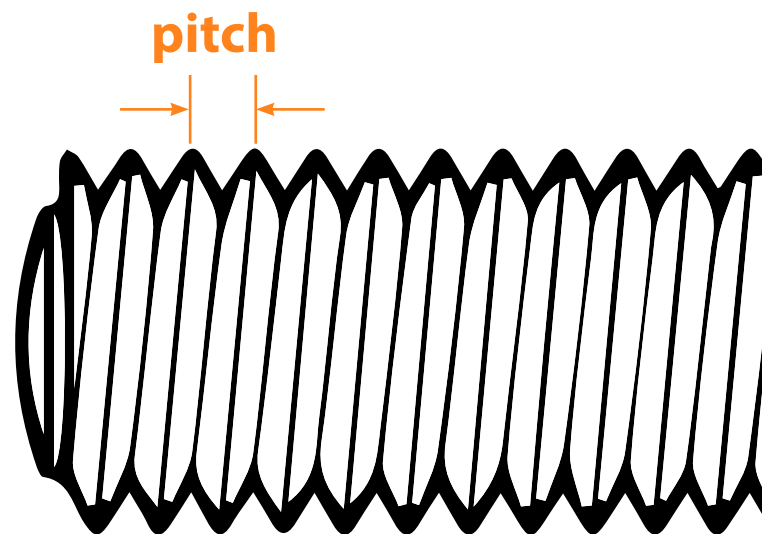


### Thread pitch

The thread pitch of a bolt is probably the most unknown property among enthusiasts. In the hardware store you will mainly find metric bolts with a standard pitch as described by DIN-ISO standards. Our VW's use metric bolts but the pitch can sometimes differ from the DIN standard. The pitch for metric threads is indicated in millimeters (for English threads it is indicated in threads per inch).

But what is thread pitch?

The thread pitch is the distance between threads expressed in millimeters (measured along the length of the fastener), it is the displacement along the axis per revolution. Or, pitch is the displacement of the screw line at one revolution as we show in the drawing below.





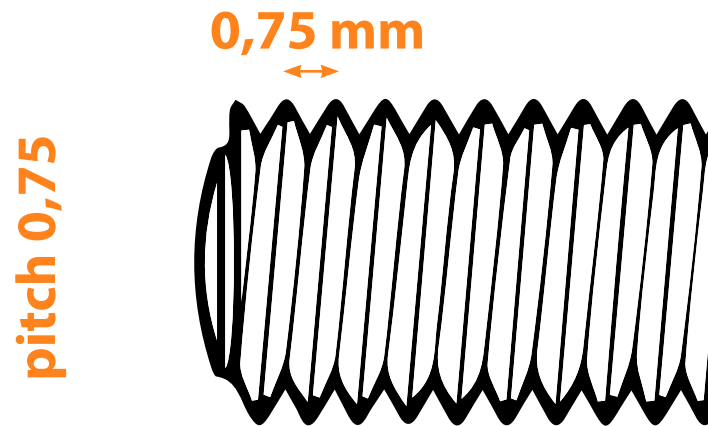
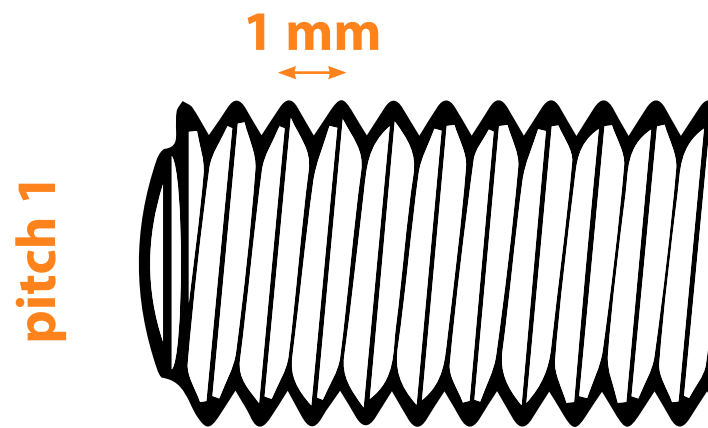
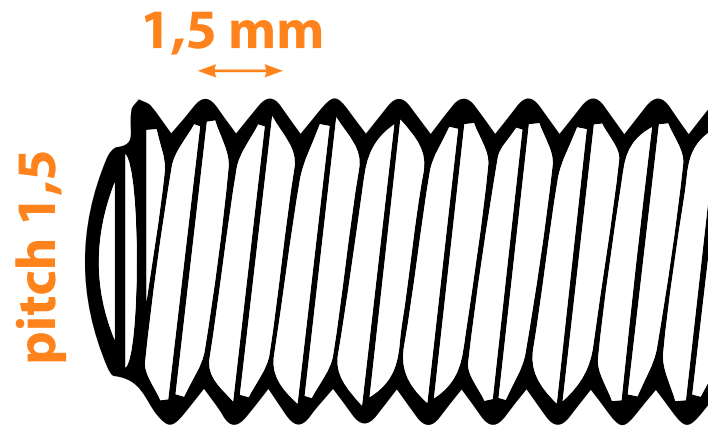
Thread pitch is expressed in millimeters for metric bolts. For a bolt with a pitch equal to 1, the thread tips are exactly 1 mm apart. With a pitch of 1.5 that is 1.5 mm, with 0.75 that is 0.75 mm, and so on.

If you try to fit a bolt with pitch 1.5 into a nut with pitch 1, both will be irreversibly damaged. If it is a nut, you can quickly find another nut (and bolt). But if it's a more difficult part to replace, such as an engine crankcase or a ball joint, the cost will quickly add up.

So the message is, measure first, then assemble.

There are bolts with standard metric pitch, fine pitch (smaller pitch is stronger because bolt retains more material, also has lower torque) and coarse pitch (larger pitch than standard).

But, how can you measure the pitch?



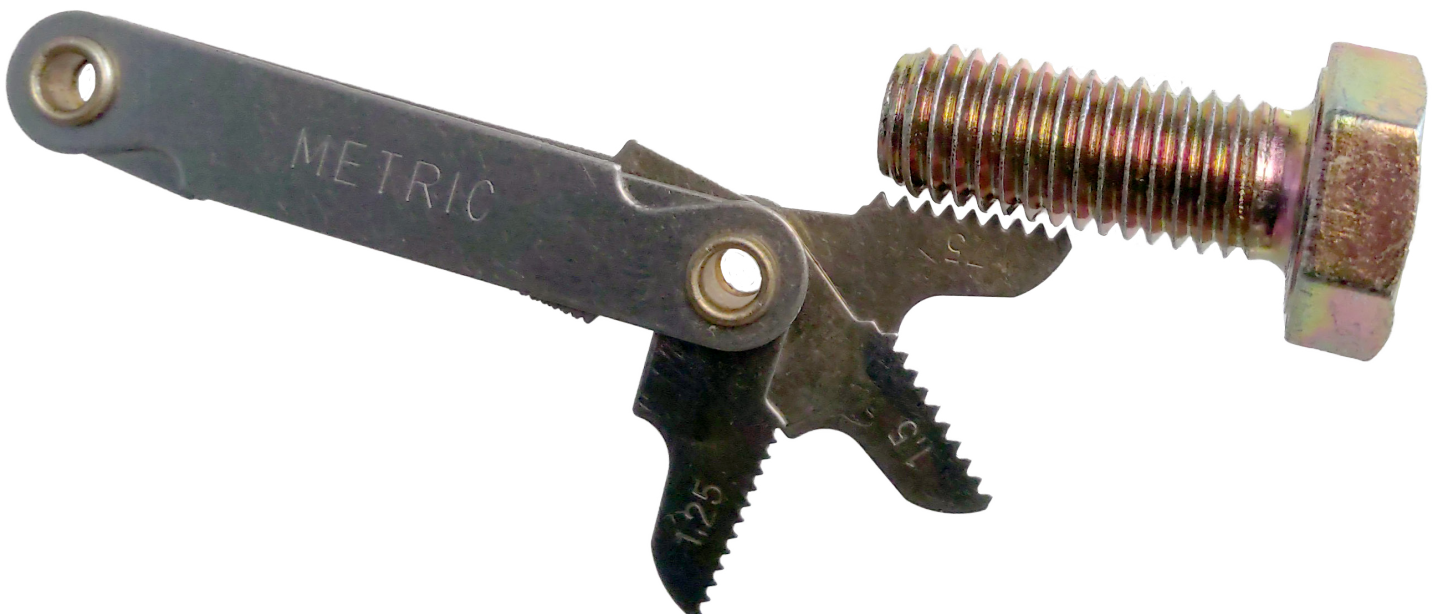
# metric bolts

The most accurate is to use a thread pitch gauge as we show in the picture on the right. These come in various forms, but what you need to buy is a metric pitch gauge. You can see the different serrations of pitch ranging from 0.5 to 2.0.

Using them is very simple, you place the saw teeth against the threads of the bolt until you have a match. Below we show a standard M12 bolt with pitch 1.75.



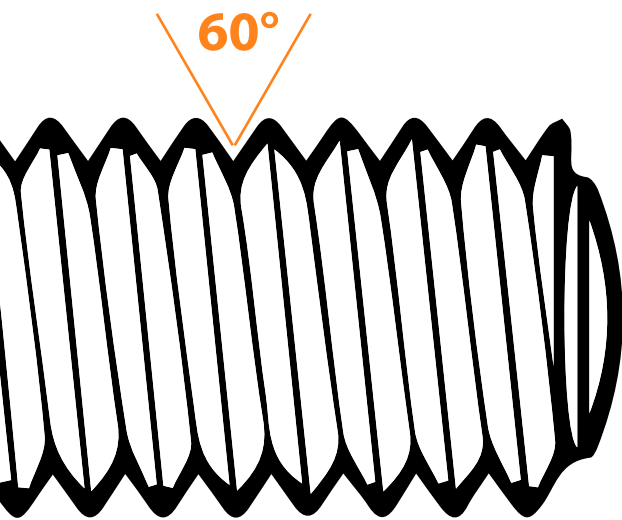
If you don't have such a measuring tool at home, you can measure the distance between 10 revolutions of the thread, and divide that by 10. Or rotate a nut 10 times on the bolt and measure the distance travelled. For our bolt below, the nut traveled exactly 1.75 cm, divide that by 10 and you come up with a pitch of 1.75 (mm). But you can't check the thread angle this way.





### Thread angle

It is recommended to use a pitch gauge because the thread angle can be different. For metric threads, the thread angle is  $60^\circ$ .



The thread angle is shown in the drawing above. Not all threads have a thread angle of  $60^\circ$ . In the English version (Whitworth) it is  $55^\circ$ . With the pitch gauge you can, if you look closely for example with a magnifying glass, see

that the thread angle of the bolt is the same as the thread angle of the gauge. If not, you should try with a Whitworth pitch gauge as shown below this particular one can handle both metric and Whitworth.

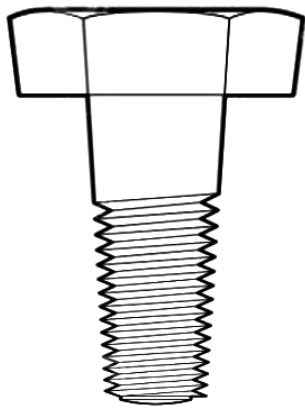
### Tapered thread

Most bolts have a straight thread, this is a cylindrical thread, that is, the width of the other thread is the same over the entire length. Standard metric bolts always have a cylindrical thread.



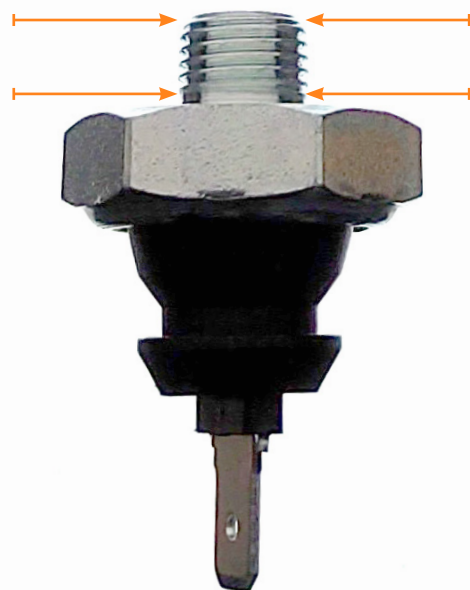
# metric bolts

There are also tapered bolts (or conical bolts) where the threads are tapered (drawing below, a little exaggerated to make it clear what we mean).



This type of bolt is used to seal for instance the gearbox oil drain or engine crankcase oil drain. They seal by themselves, without a gasket, by tightening to the prescribed torque. If tightened too hard, this type of bolt can cause the engine or gearbox crankcase to crack, so follow the VW workshop manual instructions carefully!

Another example with our classic Volkswagen is the oil pressure sensor (photos below) that screws into the engine crankcase without a gasket (as the filler plug and the gearbox drain). Tightening manually until resistance is felt is sufficient to seal. If you are going to tighten it all the way to the crankcase you risk damaging the sensor and worse, the crankcase.



9,7 mm

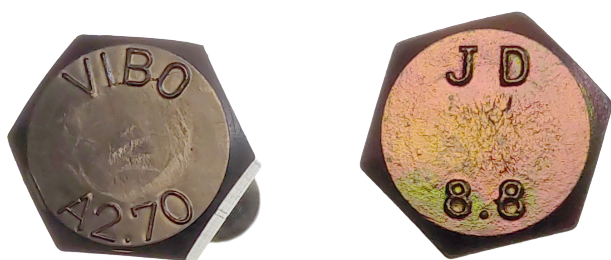
9,9 mm



## Tensile strength

This is the bolt feature that is sometimes loosely handled, unfortunately. The technical details of this are reserved for engineers specializing in mechanics and material strength theory. But what should we as VW enthusiasts remember about this?

The ISO code of tensile strength is indicated on the head of the bolt (photo below, left a 2.70 bolt, right 8.8).



On the package (for the bolts we use as an example) you will see the tensile strength and material listed in the upper right hand corner. These are M10 bolts with a tensile strength of 8.8.

Volkswagen does not specify anywhere what tensile strength is needed, it is therefore very important that you choose the bolt, screw and nut for the right application in our webstore.

We have figured all this out for you by checking the original bolts for each type of VW. If you have disassembled a bolt yourself, read the tensile strength on the bolt head before ordering

(of course this is no guarantee, a previous mechanic could have replaced the bolt).

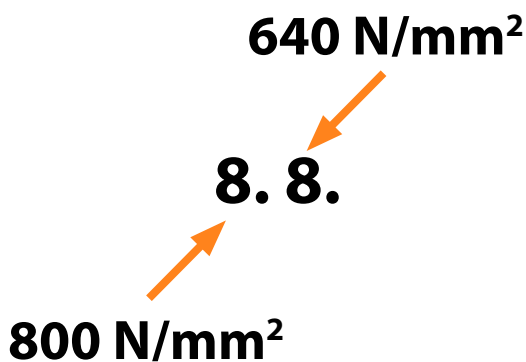
But what does 8.8 mean?



# metric bolts

The number in front of the point represents 1% of the tensile strength expressed in N/mm<sup>2</sup>. So an 8.8 bolt has a tensile strength of 800 N/mm<sup>2</sup>.

The number after the point is the yield strength. It is expressed in tenths of the percentage of tensile strength. In this case, it is 80% of 800 = 640 N/mm<sup>2</sup>.



A bolt with designation on the head 12.9. has a tensile strength of 1200 N/mm<sup>2</sup> and a yield strength of 90% of 1200 (which is equal to 1080 N/mm<sup>2</sup>).

**Tensile strength** is the tensile force required to cause the bolt to permanently change shape. That is, the bolt will stretch and no longer assume its original shape. The bolt is irrevocably damaged and will break.

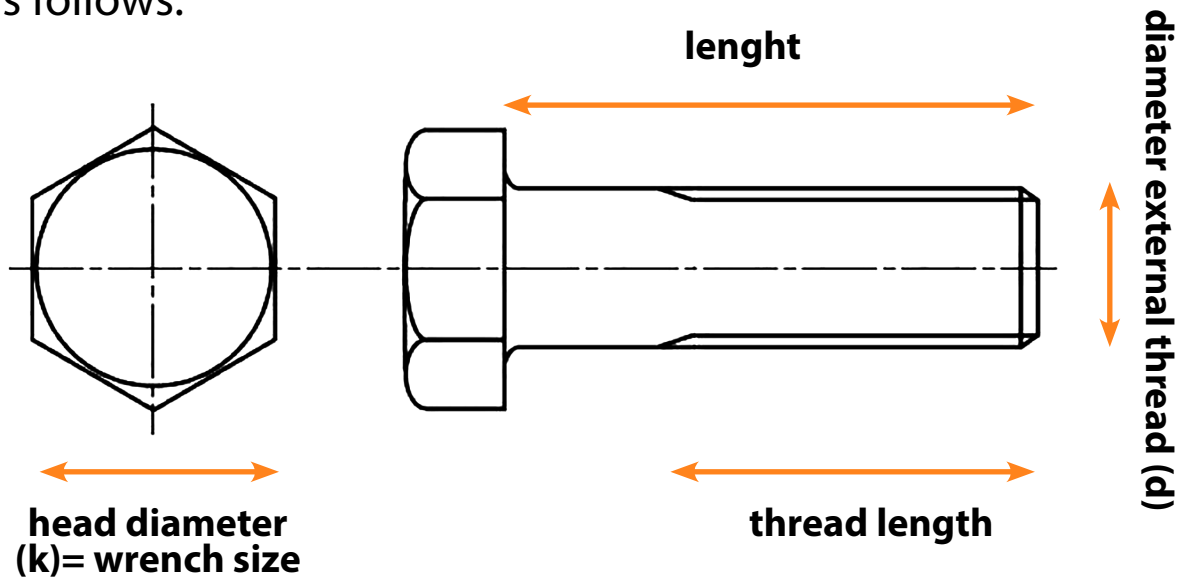
The **yield strength** (or yield stress) is the force required to cause the bolt to change shape, a plastic deformation. If this force is not maintained for too long, the bolt will return to its original shape.

Manufacturers will use bolts that are loaded below the yield strength. In some applications where there are large loads, such as flywheel, clutch or drive shafts, a tensile strength of, say, 12.9 is used.



**Dimensions**

The dimensions of bolts are indicated as follows:



Metric bolts are standardized; the table on the next page shows common values. You can tell from the table what pitch standard metric bolts have and what wrench to use to tighten them.

If you are dealing with standard metric bolts, you can also derive the tightening torque from the table. Note that the higher the tensile strength the greater the tightening torque.



Above we show a bolt from page 48, an M10, it is tightened with a wrench 17 according to the table. I wanted to check that to see if my story was correct.

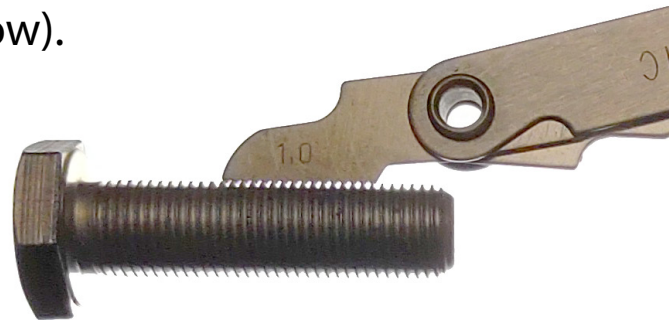


# metric bolts

## Deviating sizes

As mentioned at the beginning of this article, it is not our intention to start listing all types of bolts. We wanted to inform the reader that not only can a bolt have a different length or thickness, but other properties are at least as important. The diameter of the outer thread is listed by Volkswagen in the parts books, as well as the length and pitch but not the tensile strength unfortunately.

If you also start working with other brands, you may come across the most exotic formats, for example an M10 with a thinner head and fine thread (photo below).



In subsequent articles, we will look at such things as how to restore threads and how bolts are secured.

				tensile strength 6.8	tensile strength 8.8	tensile strength 10.9	tensile strength 12.9
	d	pitch	k	torque (Nm)			
M5	5	0,8	8	4,8	6,4	9,4	11
M6	6	1	10	8,3	11,1	16,3	19,1
M8	8	1,25	13	20	27	39	46
M10	10	1,5	17	40	53	78	92
M12	12	1,75	19	69	92	136	159
M14	14	2	21	111	148	218	255
M16	16	2	24	174	232	341	399
M18	18	2,5	27	239	330	469	549
M20	20	2,5	30	341	471	667	781



