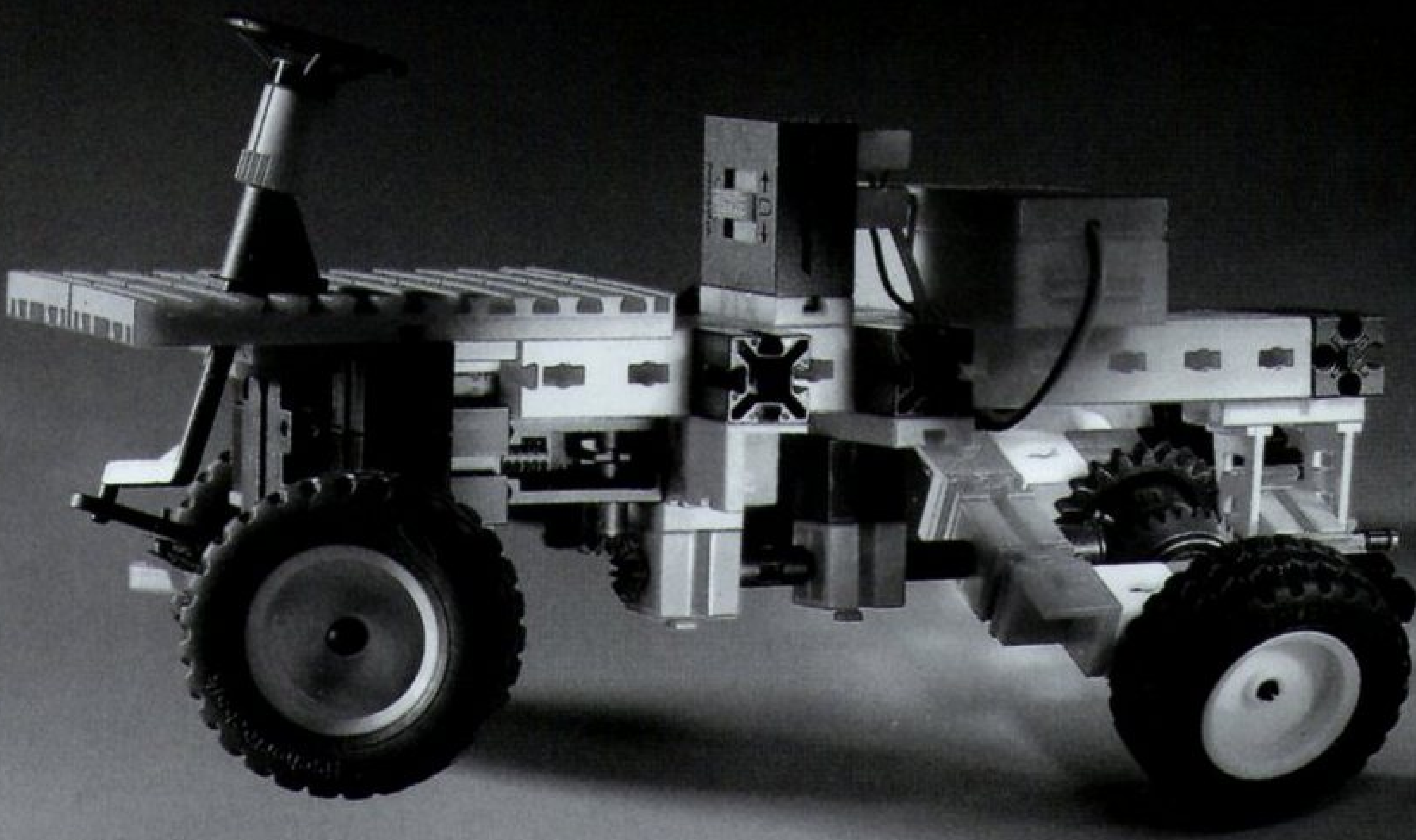
HANDBOOK / MANUEL / MANUAL / MANUALE / HANDBOEK

PROFI CARTECH



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CARTECH

Experiment Manual
Manuel d'experimentation
Experimenteerboek
Libro de Experimentos
Manuale di esperimenti

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CARTECH

Experiment Manual

English version

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Contents

All references to diagrams not contained in this manual refer to the German version of the manual.

CarTech ...

... Is the abbreviation for car technology, in other words everything that has anything to do with automotive engineering. Of course, we cannot cover every single area of automotive engineering in a fischertechnik construction kit.
We are concerned here with the two most important aspects, namely the transmission system and the steering. You will find out how to construct gearboxes with two forward gears or with a reverse gear, try out the different types of steering, get to know all the things that an off-road vehicle with four-wheel drive and a swing axle can do and experiment with the models. This is not a study book like the ones you use in school. It merely attempts to give you ideas for your own experiments, so that you can find out for yourself in a simple way how everything works.
Although the gearbox of a real car has four or more gears and a somewhat different construction, it works in basically the same way as your fischertechnik models with only two gears. Gears are not only used in cars, but also in many types of machine (e.g. in drills, washing machines or bicycles). A mechanical clock is also nothing more than a special type of gear. Gears were the most important elements of the machines used by ancient civilizations, by the way, and the drawings of Leonardo da Vinci, who lived around the end of the 15th century, show the same transmission system principles as those still used today.
Once you have built the models and understood how they work, you can also combine them with building blocks from other fischertechnik construction kits (e.g. you can add a driver's cab from the Master construction kit) or even design your own models (e.g. a crane which uses a gear for the lifting hook).

Before you start ...

... There are a few important "minor details" and tips which you should read carefully before you start to build your first model.

Assembling the mechanical components

1. Assemble the tyre (Fig. 1).

2. Tighten the hub on the axle.
Screw the hub chuck and the hub nut to the gear wheel. Then fit them onto the axle and tighten the hub nut securely (Fig. 2).

3. Assemble the steering cube and jaw (Fig. 3).

4. Assemble the hinged block claw and the hinged block tab (Fig. 4).

5. Assemble the steering wheel, hub nut and steering column.

Screw the hub nut onto the steering wheel, then fit them onto the steering column and tighten the hub nut securely (Fig. 5).

6. Assemble the chain.

Assemble the chain by fitting the individual links of the catching caterpillar together until the chain is long enough. The instructions for the models always tell you how long the chain should be (Fig. 6).

7. Sort out the various gear wheels (Fig. 7).

8. Combination of Z15 gear wheels and hub nut/collet chuck.

You must be rather careful when combining two 15 gear wheels. There is a small mark on both of them. The gear wheels can only be fitted together correctly if the two marks are aligned exactly. Place the two gear wheels one on top of the other with the marks facing in the same direction. Then insert the collet chuck through them and screw on the hub nut

(Fig. 8).

9. Assemble the universal joint (Fig. 9).

10. Assemble the differential (Fig. 10).

Assembling plugs

All cables are fitted with plugs. Fig. 11 shows you how to assemble the plugs.

Preparing cables

A two-core cable is used to connect the power supply, the motor and the switch. Carefully cut open the ends of the cables with a pair of scissors to a length of about 3 cm and pull the cores apart slightly (Fig. 12).

Stripping cables and fitting plugs

To strip the cables, score carefully around the plastic insulation with a penknife, about 4 mm from the end. Take care not to damage the fine copper cores! Then pull the plastic insulation away from the copper conductor. Bend back the copper litz wire and then screw on the plug. Undo the screw in the plug to do so, and insert the end of the cable. Then tighten the screw gently, taking care not to squeeze the insulation too hard (Fig. 13).

Plugs with the same color must be connected to both the ends of each cable core - red plugs to the red core and green plugs to the red/ green core (Fig. 14).

Power supply

The models are supplied by a 9 volt power block. The plug fits all commercial 9 volt batteries (Fig. 15).

Fig. 15:
The batterie is not part of the package.
Do not keep batteries in the model for too long! If you do not intend to use the model for some time, we advise you to take the batteries out of the model. Only throw away spent batteries at disposal centres for hazardous waste.

Motor

DC electric motor with three connection options (see Fig. 16). You can combine the connection options (e.g. insert the right plug in the front and the left plug in the top). NEVER insert the two plugs in the same side of the motor. This will produce a short circuit.

The basics of electrical engineering

The models are all driven by an electric motor. You therefore need to know the basics of electrical engineering:
Not all substances conduct electricity equally well. A current flows especially well in metals, for example in the thin copper wires used in fischertechnik kits. Brass, iron, lead, tin and bare fischertechnik metal axles are also good conductors. If two conductors come into contact with one another, the current can also flow across the point of contact (we benefit from this characteristic, for example, when we connect plugs and sockets).
Other substances are either poor conductors of electricity or do not conduct it at all. This is the reason for using plastic to protect the copper cores of the cables against accidental contact, plastic being a so-called "insulator", i.e. a definite non-conductor. Air, glass, dry wood and the majority of non-metal substances are also insulators.
A power source, e.g. a battery or a separate power supply unit, is needed to operate electrical loads (lamps, electromagnets, motors). Imagine the power source to be like a water pump, which pushes the electricity through the cables and the loads. Like the pump in an aquarium, it needs a closed circuit for the current to be able to flow (Fig. 17). The electricity flows through the "go" line to the load and then back through the "return" line to the battery. If the circuit is interrupted at any point, the electricity is no longer able to flow.
In the CarTech models, the current normally flows from the battery to the motor via the reversing switch. Try connecting the battery plugs directly to the motor and watch the direction of rotation. Then swap the two plugs

around at the motor - it will then turn in the opposite direction.

Swapping the connections around in other words reverses the direction of rotation. This is a very complicated way of doing things however. It is much more practical to use the reversing switch, which not only swaps the motor connections around (it reverses them), but also switches off the motor in its mid-position.

The reversing switch has two pairs of sockets, marked "battery" and "motor". Connect the two plugs connected to the battery to the two "battery" sockets. Then connect the cable from the motor to the two "motor" sockets (Fig. 18).

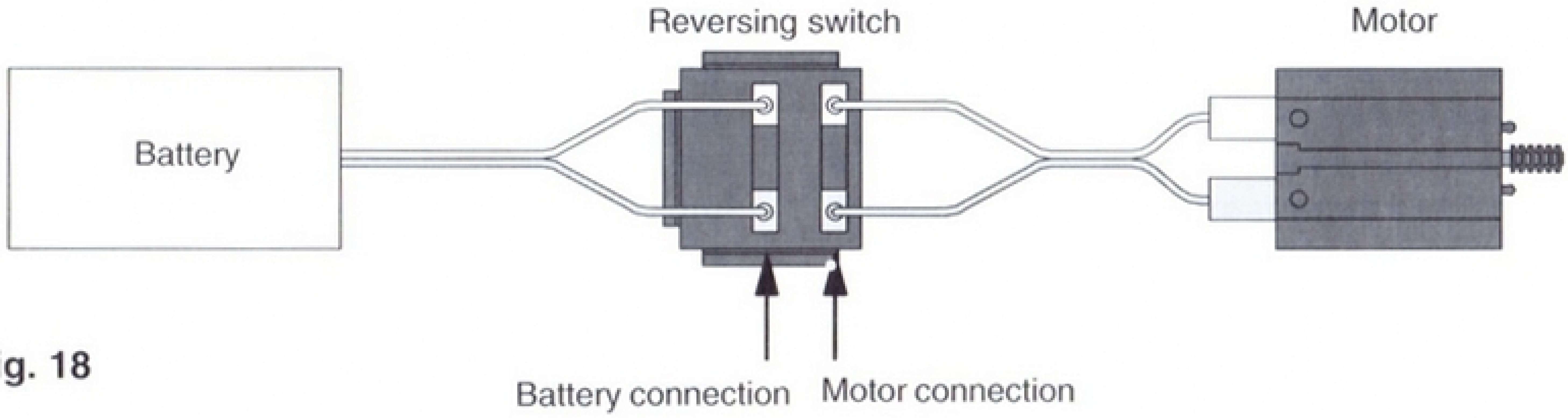


Fig. 18

Building the models

The models themselves must be constructed step by step, as shown in the assembly diagrams. Each time you proceed to the next step, the new components are illustrated in color. If they must be built onto a part which is already assembled, this part is shown in white. Before you begin a new step, sort out all the components you need and then build them onto your model. The next step never starts until you have used up all the parts. Make sure that you fit the building blocks the right way round, so that you don't get stuck later on.

It's also very important to tighten all the axle screwings (e.g. hubs) properly, or the models will not work.

That's all the preparation you need. You are now ready to read through this instruction manual at your leisure, and to stop to browse every now and then if you find something interesting.

The secret of power transmission

With many of the CarTech models, the rotary movement of the motor is transferred to the wheels via a chain - just like the one you can find on a bicycle. If you take a look at the chain of your bicycle, there may be something that puzzles you about the chain and the two gear wheels: why is the front gear wheel bigger than the rear one?

By the time you've discovered the point behind this question, you will already have gained a grasp of the basic technical concepts of gears. From power transmission with a gear wheel to gear shifting (like the dérailleur on your bike) is only a small step. Before you build the first model, just have a little think about what goes into driving a vehicle or a machine.

> For a start, you need a driving mechanism. On a bicycle this is the pedals, while in the fischertechnik models it is an electric motor.
>
> Next, you have to have power trans

mission between the driving system and the driven parts, e.g. the chain on a bicycle or the gear wheels in a car gearbox.

You will also find chain and gear-wheel transmission systems in the fischertechnik models.

At the end of the power transmission section are the parts which are actually driven, e.g. the car wheels, a drill, the door of a lift - or whatever it is that is supposed to be moved.

Sometimes there is no power transmission section at all, e.g. in a fan, where the propeller is mounted directly on the motor axle. Most of the time, however, the high rotary speed of the motor is not required; it must be reduced by means of a gear. This has a very desirable side-effect: the power of the motor increases as its speed is reduced.
In a minute you will be able to find out how this works by experimenting with the first model. The various steps are shown on pages 19-20 of the German manual. You can use this model to discover the effect of different gear wheels on a chain drive. You can tauten the chain when you change between large and small gear wheels by displacing the left-hand shaft bearing on the base plate. But now it's time to set to work (the abbreviation "gear wheel 20" stands for "gear wheel with 20 teeth") - and pay attention to the speed of the two tyres:

Experiment 1: Left-hand gear wheel 20, right-hand gear wheel 20
Experiment 2: Left-hand gear wheel 10, right-hand gear wheel 10
Experiment 3: Left-hand gear wheel 20, right-hand gear wheel 10
Experiment 4: Left-hand gear wheel 10, right-hand gear wheel 20

How does it work?

Have you worked it out? With the first two experiments, the two tyres turn at the same speed, even though the gear wheels used for the first experiment have twice as many teeth as those used for the second experiment. With the third experiment, the left-hand tyre turns more slowly than the right-hand tyre, while with the last experiment, the opposite is the case, i.e. the left-hand tyre is faster. The next step is to find out how much faster or slower the left-hand tyre is turning.
This is quite simple to imagine. The chain forms a rigid link and nothing can be displaced at all. What happens when the right-hand gear wheel has 10 teeth and the left-hand wheel has 20 teeth? Let's assume that the right-hand gear wheel turns one complete turn. The chain will have moved on exactly 10 teeth - and since the link is rigid, the left-hand gear wheel must also have moved on 10 teeth. Since the left-hand gear wheel has 20 teeth however, it only turns half a turn. If the right-hand gear wheel is now turned another complete turn, the left-hand wheel will have turned exactly one full turn - in other words, it turns exactly half as fast as the right-hand wheel.
You can also try this out yourself if you displace the gear slightly on the motor (the motor is disconnected from the drive) and turn the tyres by hand. You will find it easier to count the turns if you mark the gear wheels with a small piece of adhesive tape. (Be careful not to get the tape stuck in the chain!) If you arrange the gear wheels for the fourth experiment, the result will be the exact opposite, i.e. the left-hand gear wheel will turn twice as fast as the right-hand wheel (Fig. 19). With the first two experiments, the two tyres turned at the same speed and a vehicle would also travel at the same speed. It therefore obviously makes no difference how many teeth the gear wheels have - only the ratio of the number of teeth on the two wheels is important. Imagine for a moment what would happen if the left-hand gear wheel had 40 teeth and the right-hand wheel 20: the right-hand gear wheel would have to turn twice for the left-hand wheel to turn once - in other words the ratio would be the same as before.
With what you now know, you are ready to start calculating transmissions. Since the number of teeth is irrelevant to power transmission, and only the ratio of the number of teeth on the two wheels matters, a special term is used in engineering to describe this ratio. The motor (or engine) speed is geared

either up or down, and the tooth ratio is known as the "transmission ratio", the "gear ratio" or the "speed-reducing/increasing ratio".

You can now continue by working out the transmission ratios for the examples described above:

20:40 = 10:20 = 1:2

As you can see, the only arithmetic you need to know is how to cancel out the fractions. You can also work out the transmission ratios for the four experiments. If you are not quite sure yet, you can cheat by looking them up in the table below (we have used a colon instead of the dividing line for the fractions, to make things clearer).

Exp. no.	Teeth on left tyre	Teeth on right transmission	Transmission ratio
1	20	20	20:20 = 1:1
2	10	10	10:10 = 1:1
3	20	10	20:10 = 2:1
4	10	20	10:20 = 1:2

The transmission ratio also tells you straight away whether the driven (left-hand) tyre is turning faster or slower than the tyre on the (right-hand) motor shaft:

If the number in front of the colon is higher than the number after the colon, the speed is reduced.

If the number in front of the colon is lower than the number after the colon, the speed is increased.

You should now be able to answer the question at the start of the chapter. The front gear wheel of a bicycle next to the pedals is bigger so that you don't have to pedal away like crazy in order to get anywhere.

Gears for tractors, racing cars and off-road vehicles

You can now put the principle of power transmission with a chain and gear wheels into practice in the first model vehicles. You will also discover something about the relationship between the transmission ratio and the motive force which acts on the wheels.

The basic design of the next three models is the same - they merely differ in the manner in which the wheels are driven. The various steps are shown on pages 27-32 of the German manual.

The gear wheel on the motor shaft of the first vehicle has 10 teeth, and the gear wheel on the axle has 20. The transmission ratio is thus 2:1 and the vehicle travels slowly (e.g. a tractor).

The arrangement for the second vehicle is exactly the opposite - the 20 gear wheel is mounted on the motor shaft and the 10 gear wheel on the axle. The transmission ratio is 1:2 and the vehicle travels four times as fast as the first one (e.g. a racing car).

Both the axles of the third vehicle are

driven. Two 20 gear wheels are used on the right-hand side (when looking in the direction of travel) and two 10 gear wheels on the left-hand side. The transmission ratio is the same on both sides, namely 1:1 (off-road vehicle with four-wheel drive). The vehicle thus travels half as fast as the racing car and twice as fast as the tractor.

You can also try out each of these models to determine how they behave on a gradient. To do so, build a slope with cardboard or with a wooden board, and adjust the angle of it by placing building blocks or books underneath. Start with the tractor. Make the slope steeper a little at a time until the tractor can only just make it up. The surface of the cardboard or of the wooden board shouldn't be too smooth, or the wheels will spin. Then get the racing car to show what it can do, and finally the off-road vehicle.
If you want, you can adapt the off-road vehicle by mounting a 10 gear wheel on the motor axles on both sides and a 20 gear wheel on the two stub axles - what you now have is a combination of the tractor's transmission ratio and four-wheel drive.

How does it work?

If the surface was not too smooth, the tractor ought to have made it up a much steeper track than the racing car. This means that the power of the wheels must also depend on the transmission ratio, since the power of the motor (or engine) is the same for all models. An engineer would call this "torque" - something you'll learn about in more detail sooner or later in physics; all you need to remember as far as your fischertechnik models are concerned is this simple rule:

The torque changes in inverse proportion to the transmission ratio.

What does this mean? The model vehicles demonstrated two examples of the torque changing: the motor speed of the tractor was halved and its torque was doubled. The opposite was true of the racing car. Its torque was halved and its motor speed was doubled. This is why the tractor is able to make it up a steeper gradient. This is all summarized in the table below:

Vehicle	Tyre teeth	Transm. teeth	Transmission ratio	Torque
Off-road	20	20	20:20 = 1:1	1x
Off-road	10	10	10:10 = 1:1	1x
Tractor	20	10	10:10 = 2:1	2x
Racing Car	10	20	10:20 = 1:2	1/2x

This is also the reason, by the way, why the largest gear wheel of a dérailleur next to the back wheel of a bicycle is responsible for climbing hills (high torque, low speed) and the smallest gear wheel for travelling fast (lower torque, high speed).

Gearboxes

In the model vehicles you have built so far, a chain was necessary to bridge the distance between the motor axle and the stub axle. The gearbox of a car, which is actuated with the gear lever, should take up as little space as possible on the other hand. The gear wheels are therefore allowed to engage in one another directly. This doesn't affect the transmission ratio or the torque (because the chain forms a rigid link). You have already seen gear wheels engaging in the reducing gear at the motor.

You are probably asking why we even need a gearbox at all, seeing as you can alter the speed of a car engine just by pressing the accelerator.
Most engines don't produce the same power in every speed range (the same also applies to electric motors). The idea of having a gearbox is therefore to let the engine run in the most suitable speed range the whole time. It enables the speed of the vehicle to be adapted over a wide range to the optimum engine speed range. This is also the engine speed range in which the car makes the most efficient use of the energy contained in its

petrol. The car moreover needs a lot of power to start up, since its whole weight must be set in motion from zero. Once the car is travelling at a constant speed, it only needs to overcome the drag (the resistance put up by the air) and the friction resistance of the wheels.

Two-speed gear

You can also build proper change-speed gears with your fischertechnik kit. Your models only have two gears however, to avoid making things too complicated. Fig. 20 shows the principle of speed reduction using gear wheels as opposed to a chain drive; the only difference from the power transmission system we used earlier is that there is no chain. Have you noticed, by the way, that the vehicle wheel turns in the opposite direction to the motor shaft when the power is transferred via gear wheels? We can solve this problem with the reversing switch however.
All we need now, in order to build a "gearbox", is a mechanical construction which allows the gear wheels to engage alternately, so that you can change speeds between "fast" and "slow". The next model contains just the mechanism we want, so let's get to work again. You should choose a distance between the two pairs of gear wheels on the shaft which results in a narrow "idling" range (or coasting range) when you change gear. This permits the teeth to engage better. The various steps are shown on pages 37-38 of the German manual.

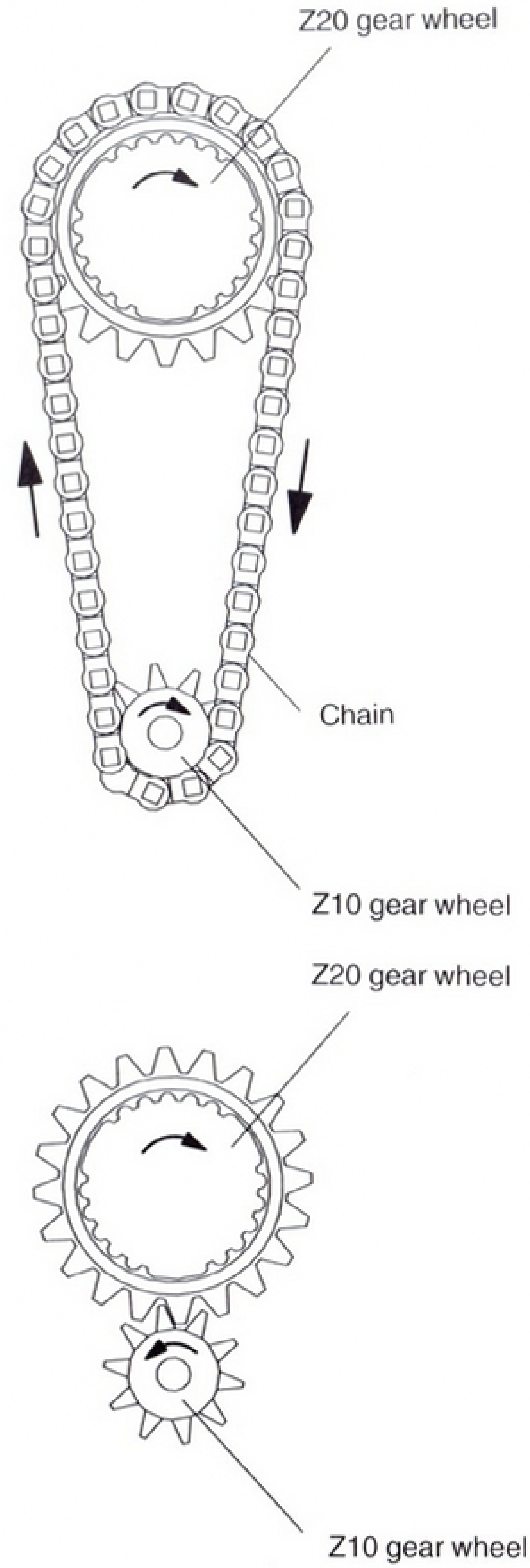
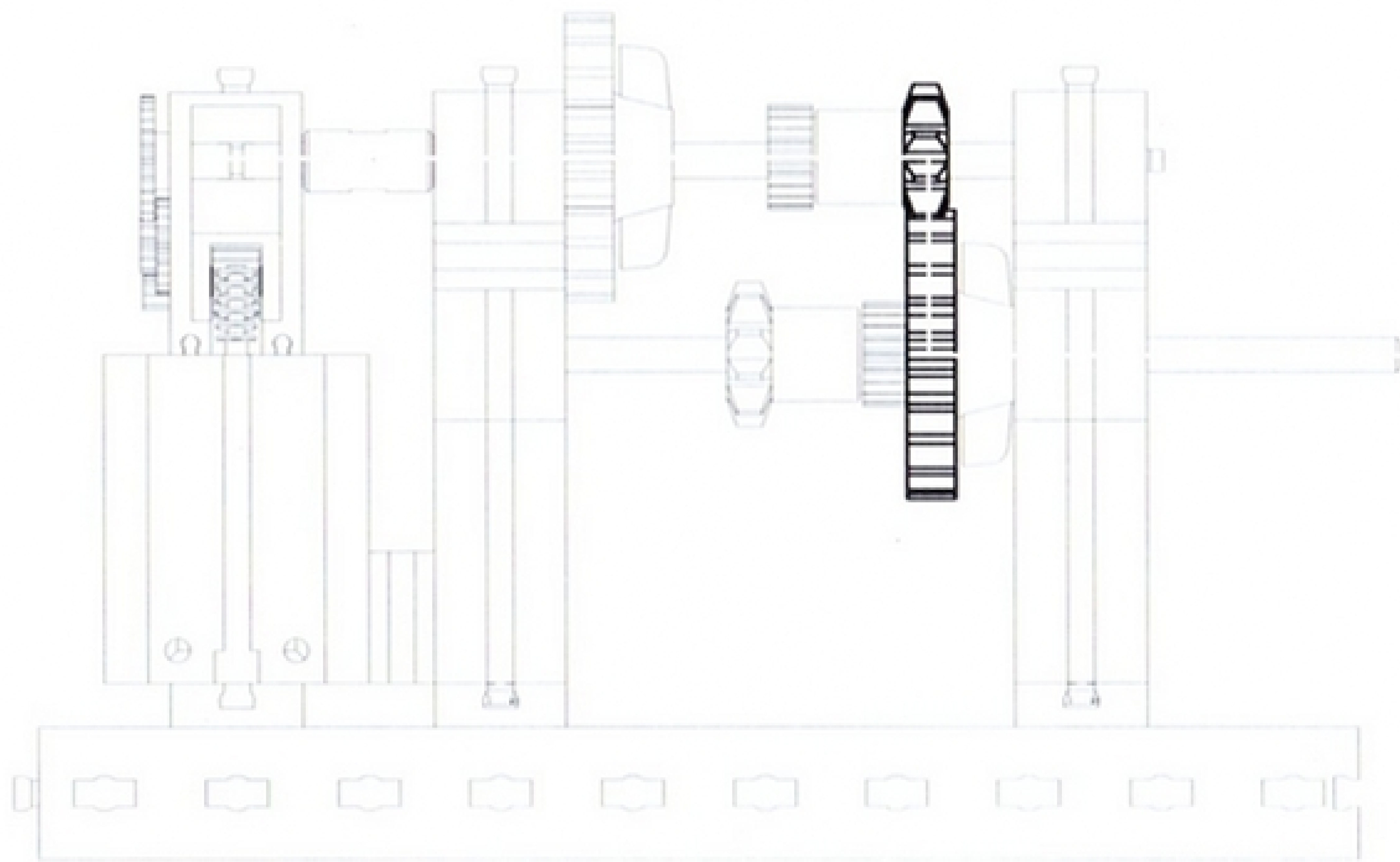
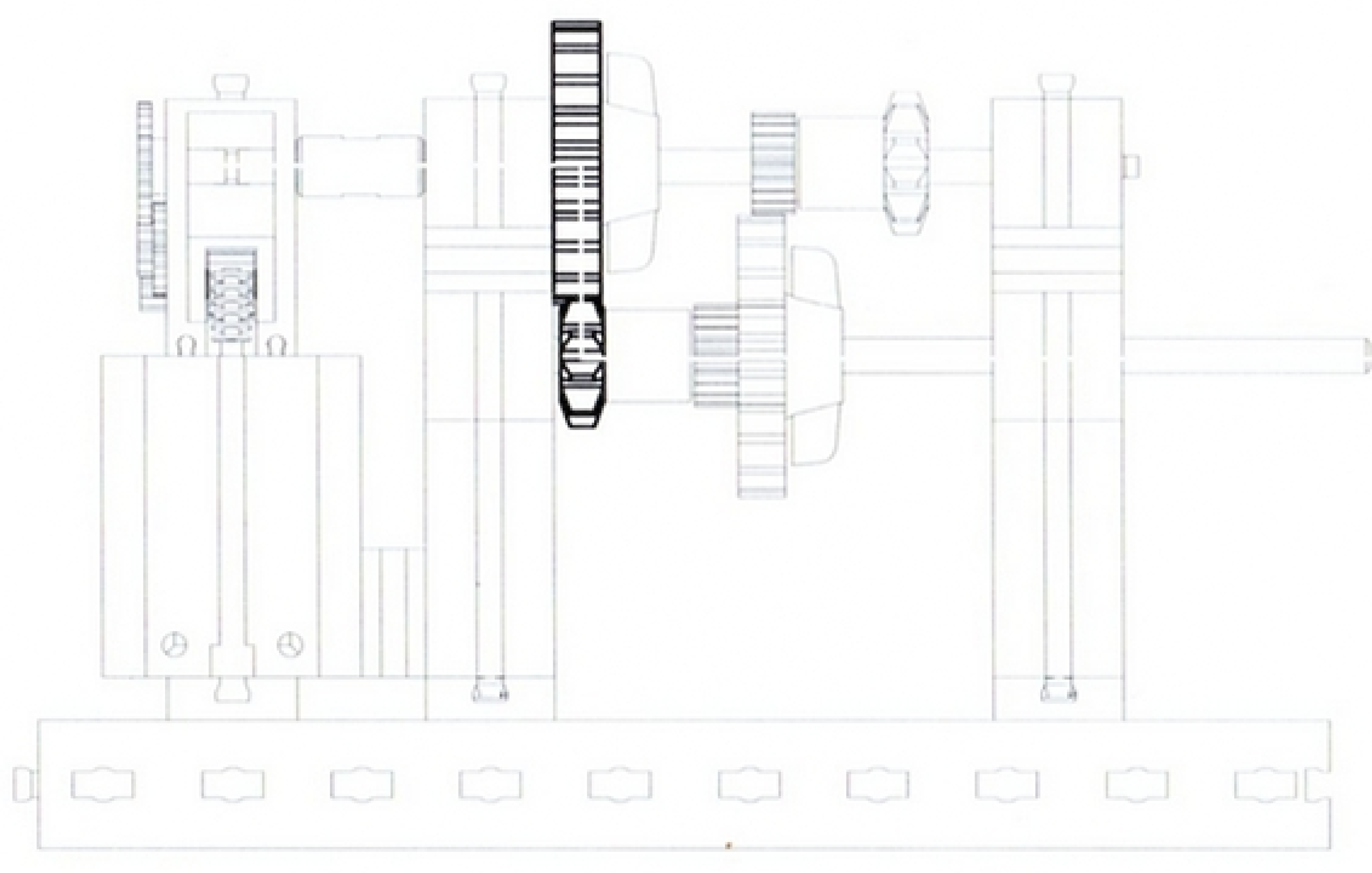


Fig. 20

1st gear



2nd gear



Now have a go at seeing how the gearbox works. It can only do so properly if the motor is running, since otherwise the teeth will not always coincide when the gear wheels engage - the result will be that you won't be able to change gear. When the motor is running, the teeth mesh easily due to the bevelled edge.
If the gear lever is set so that it points towards the motor, a 20 gear wheel on the drive shaft (which as you already know is the shaft which is driven by the motor) will engage in a 10 gear wheel on the driven shaft (which is the one with the wheel rim on the end). The transmission ratio is now as follows:

10:20 = 1:2,

which means that the wheel rim is turning at twice the speed of the motor (2nd gear).
Now press the gear lever in the opposite direction. The 10 gear wheel on the drive shaft engages in the 20 gear wheel on the driven shaft. The transmission ratio is reversed, and is now as follows:

20:10 = 2:1,

so that the wheel rim is turning at half the speed of the motor (1st gear).

Vehicle with gearbox

The "gearbox" must be installed flat in the vehicle and somewhere where it takes up as little space as possible, as shown for the next model (the various steps are shown on pages 41-43 of the German manual). The vehicle has two gears - a fast gear with a transmission ratio of

10:20 = 1:2

and a slow gear with the opposite ratio, namely

20:10 = 2:1

The vehicle thus travels four times as fast in the fast gear as in the slow gear.
There is another transmission process between the motor and the gearbox, but it has the same effect on both gear speeds. Two 15 gear wheels are mounted next to one another on the motor shaft; they transfer the power of the motor to a 20 gear wheel at the gearbox. The transmission ratio is thus:

20:15 = 4:3

The vehicle is therefore somewhat slower overall than with the stationary gearbox.

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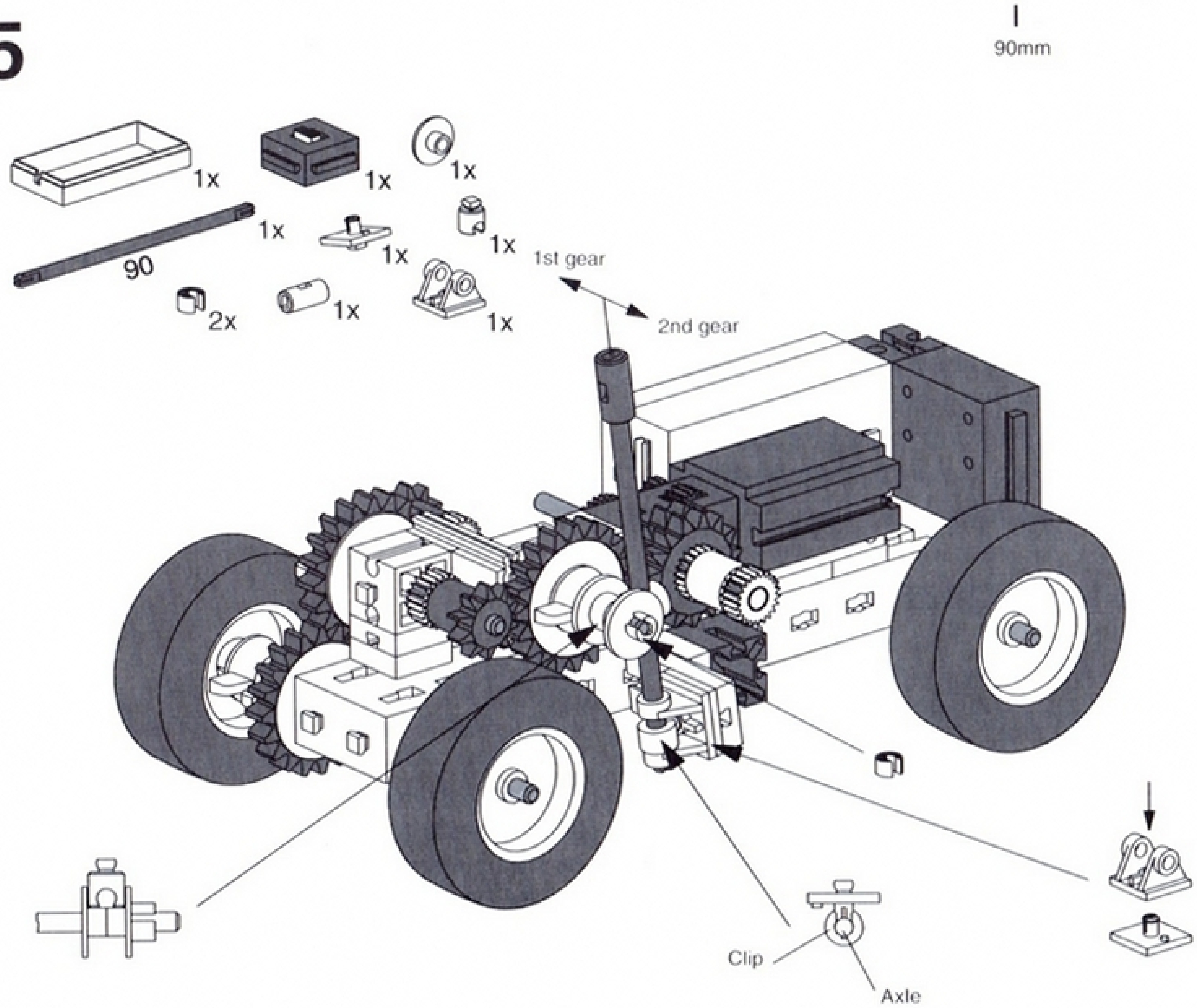
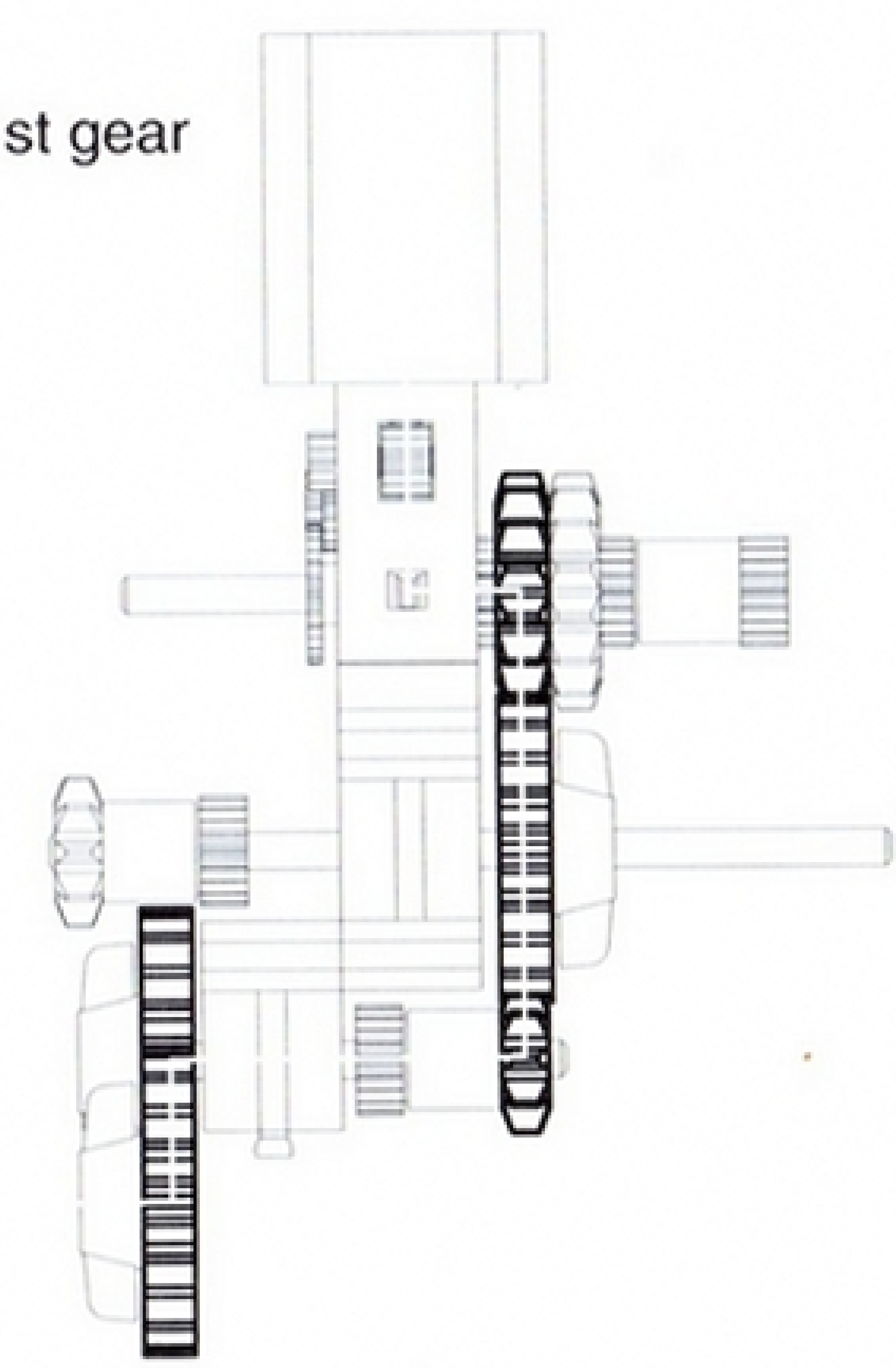
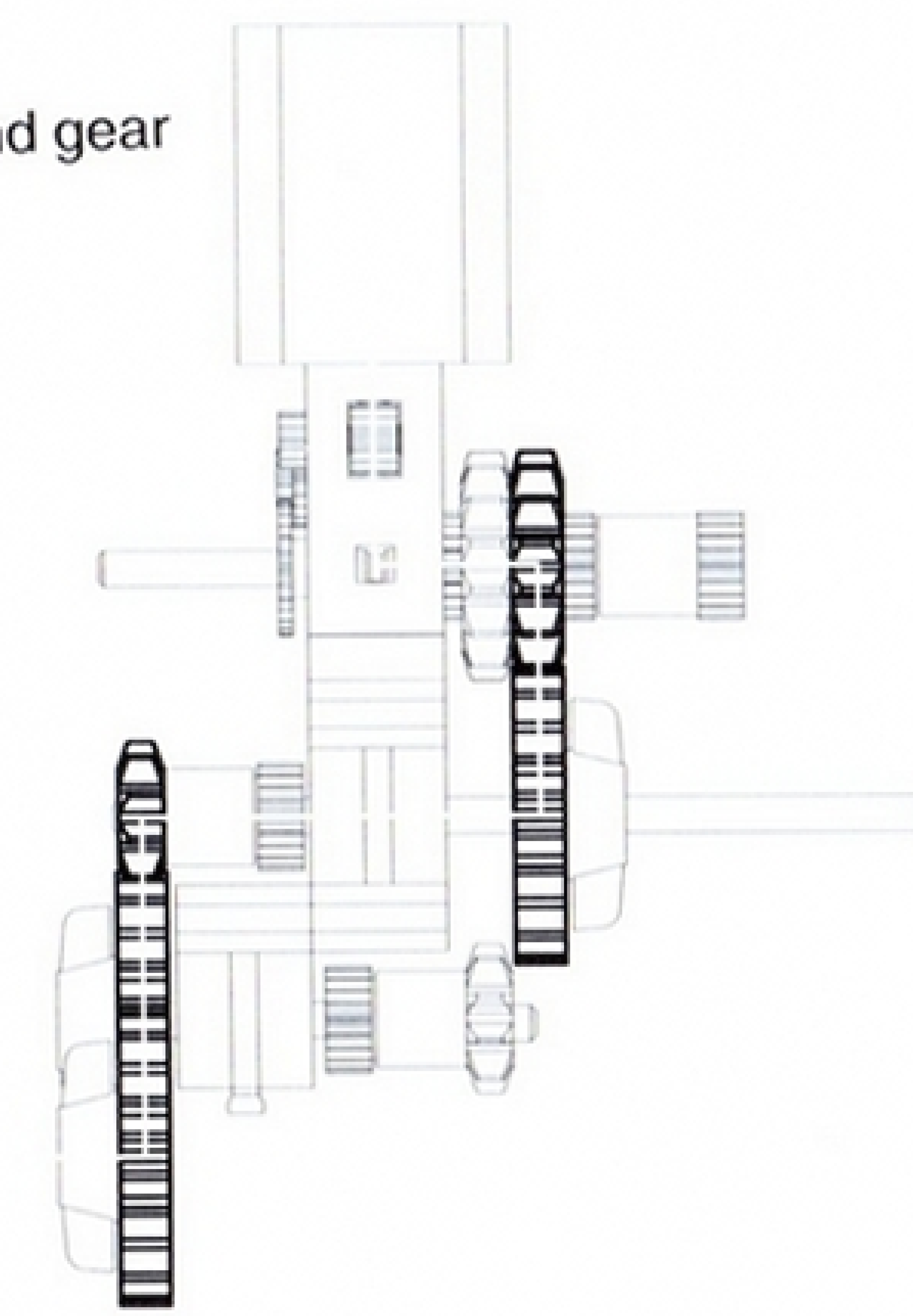


1st gear



2nd gear



How does it work?

The last model contained two transmission systems connected in series with one another, and it would be interesting to find out what the transmission ratio is between the motor shaft and the stub axle.
A rule that you have already applied to calculations for the other models you have built so far is important again here. The formula for working out the transmission ratio is as follows:

> The number of teeth on the driven gear wheel is specified above the fraction line.
>
> The number of teeth on the driving gear wheel is specified below the fraction line.

If the transmission systems are connected in series, a series of calculations must be performed as well. This is easier to understand if you write out the whole calculation with fraction lines; first of all for the slow gear:

20:15 x 10:20 = 20x10 : 15x20 = 200:300 = 2:3

And now the same again for the fast gear:

20:15 x 20:10 = 20x10 : 15x10 = 400:150 = 8:3

Now put this rule to the test: three turns of the motor shaft in the slow gear should lead to two turns of the wheel; in the fast gear the same three turns of the motor shaft result in eight turns of the wheel, in other words exactly four times as many - just as we said at the beginning. As every gearbox expert knows:

> If transmission systems are connected in series, the individual transmission ratios must be multiplied together.

We have left one transmission ratio out of our calculation: the 20:20 ratio between the gearbox and the wheel. Since this transmission ratio is 1:1 however, it has no effect on the overall result.

Gearbox with reverse gear

The gearbox of a car also has another important function. Since the car engine cannot simply be reversed the way an electric motor can, but always turns in the same direction, we must find a way of reversing the direction of rotation of the wheels (can you imagine what a nuisance it would be if you had to get out and push every time you wanted to reverse into a parking space?).

> The gearbox is thus a mechanism which converts both the speed of rotation and the direction of the wheels.

In our gearbox, which has a forward gear and a reverse gear (Fig. 21), an additional, free-wheeling gear wheel must be mounted on an intermediate shaft for one of the two rotation directions, since whereas two gear wheels reverse the direction of rotation, if there are three gear wheels, the drive shaft and the driven shaft rotate in the same direction. The same rule of course also applies if there are more than three gear wheels:

> Even number of gear wheels: rotation direction reversed
>
> Odd number of gear wheels: rotation direction stays the same

So that the distance between the drive shaft and the driven shaft can remain constant, we use three 10 gear wheels for one direction and two 20 wheels for the other direction.
You can now build your own change-speed gear (with a forward gear and a reverse gear). You will need an intermediate shaft, so that sometimes three gear wheels are active and sometimes two. If there are three gear wheels, the direction of rotation of the motor remains unchanged (as shown in Fig. 21), while with two gear wheels the direction is reversed for travelling backwards. The transmission ratio

is the same in both directions, since

$10:10 = 20:20 = 1:1$

The various steps for this model are shown on pages 46-47 of the German manual.

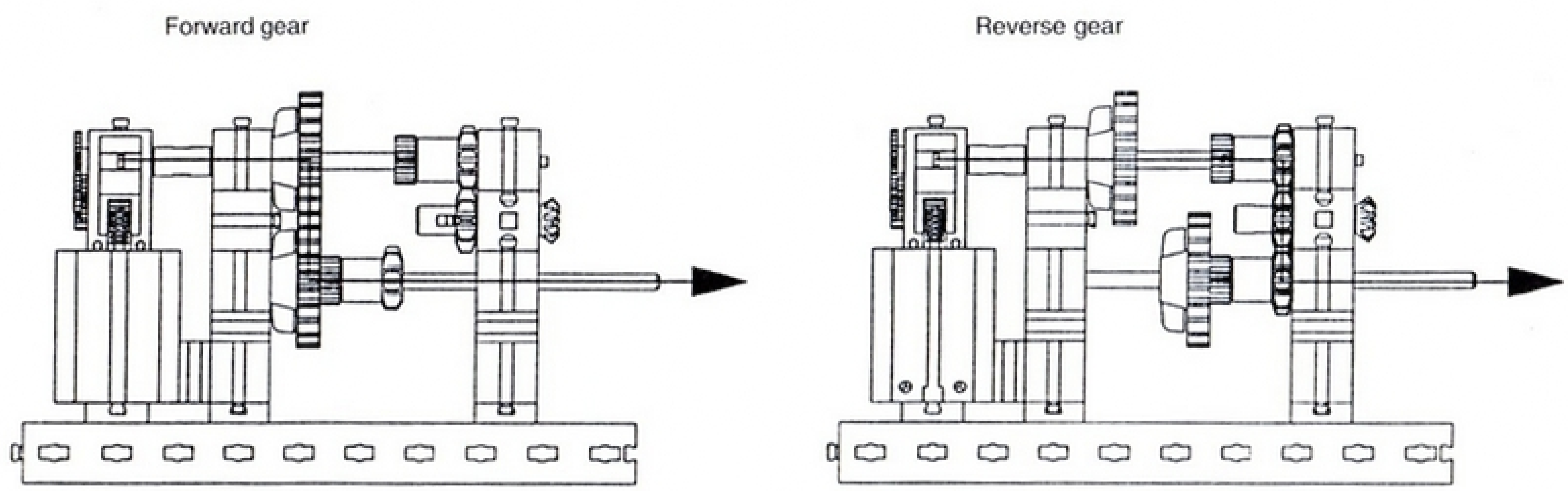
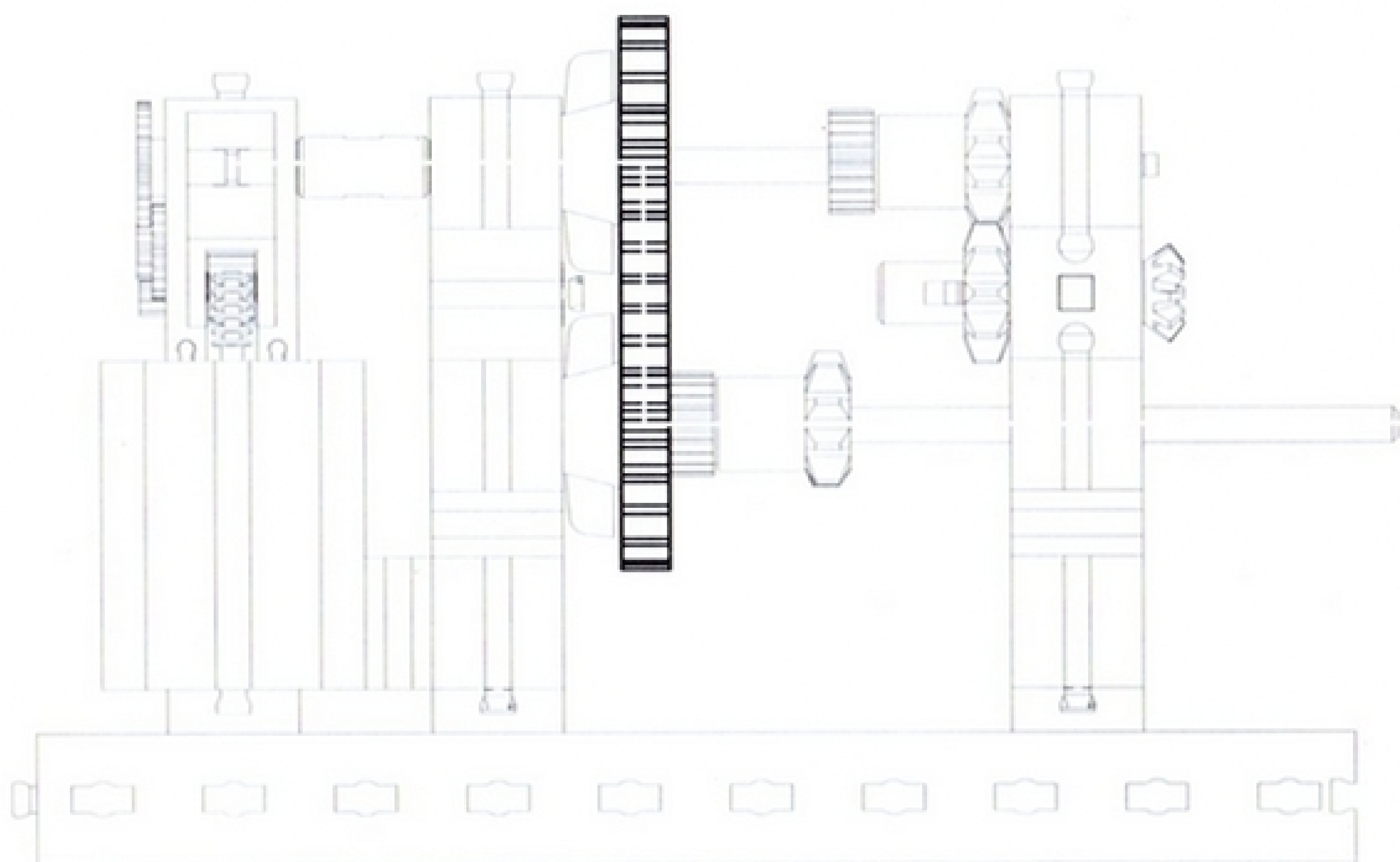
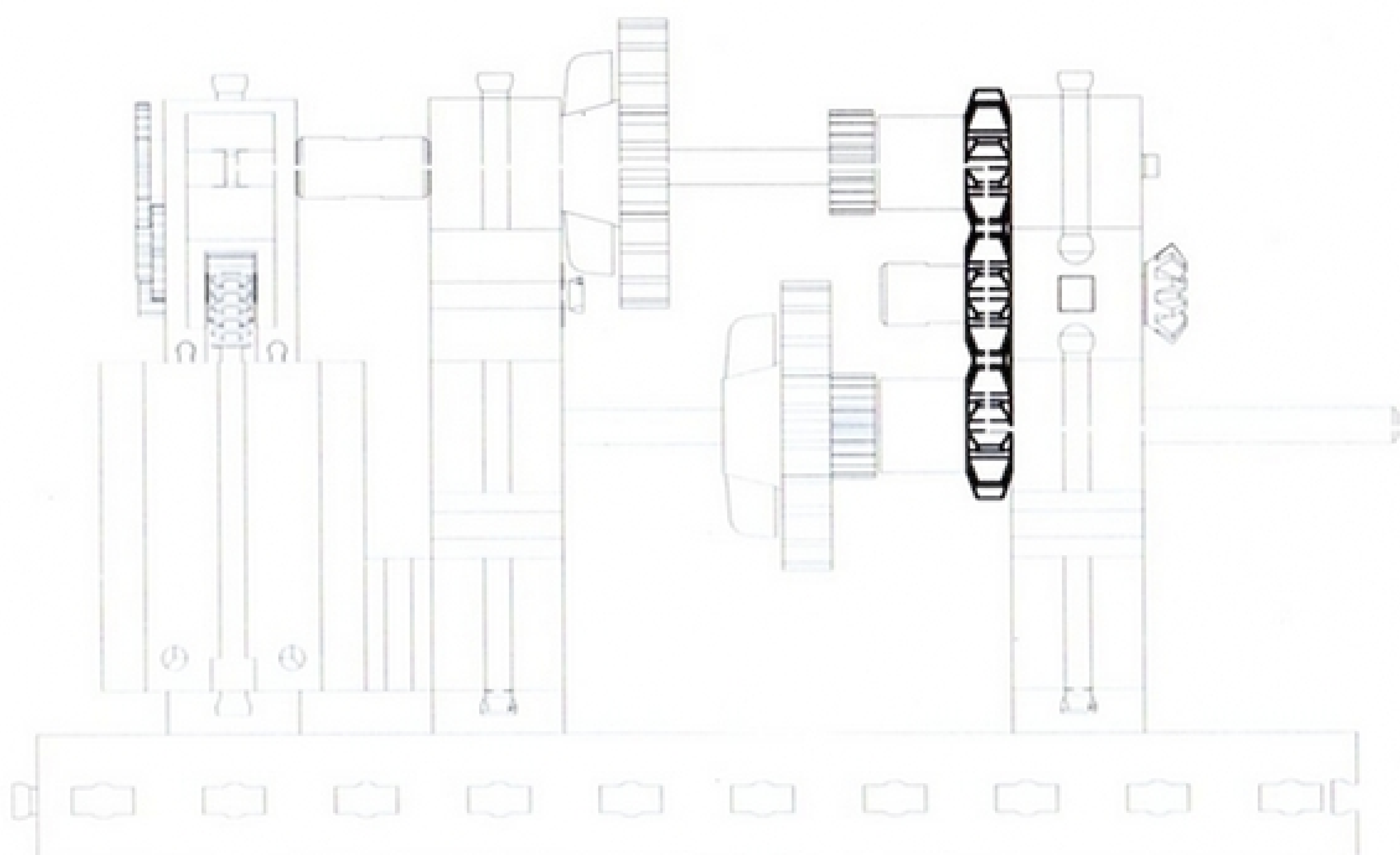


Fig. 21

Forward gear



Reverse gear



Vehicle with reverse gear

(The various steps are shown on pages 50-52 of the German manual.)

Your first vehicle with a reverse gear has rear-wheel drive (the reversing switch and the battery are at the front). If you look at the model from the back, the forward gear is engaged when the gear lever is pointing towards the right (if the model moves backwards instead, just reset the reversing switch to point in the other direction). The "gearbox" of this model has a slightly different construction, but works in exactly the same way as that of the previous model. The forward gear is formed by the two 20 gear wheels (you can forget the gear wheels on the motor and stub axles for the time being). Power is transmitted by only two gear wheels, in other words the direction of rotation of the motor shaft is reversed. If you now push the gear lever over to the left, power will be transmitted instead by means of three 10 gear wheels on the left-hand side of the gearbox - the rotation direction of the motor remains the same.
And what about the transmission ratio? You could of course start doing your sums straight away, the way you learnt earlier. But if you stop to think for a minute, there is a way of making things easier for yourself. You have discovered that with the stationary gearbox in the previous model, the transmission ratio of the gearbox itself does not change. There are thus only two things you need to pay attention to when you calculate it:

> Transmission ratio between the motor shaft and the gearbox
>
> Transmission ratio between the gearbox and the wheel

These are both simple to work out:

> Motor - gearbox:
> 15 teeth - 20 teeth
>
> Gearbox - wheel:
> 10 teeth - 20 teeth

The overall transmission ratio is therefore as follows:

20:15 x 20:10 = 400:150 = 8:3

In other words, if the motor turns eight revolutions, the wheel only turns three times.

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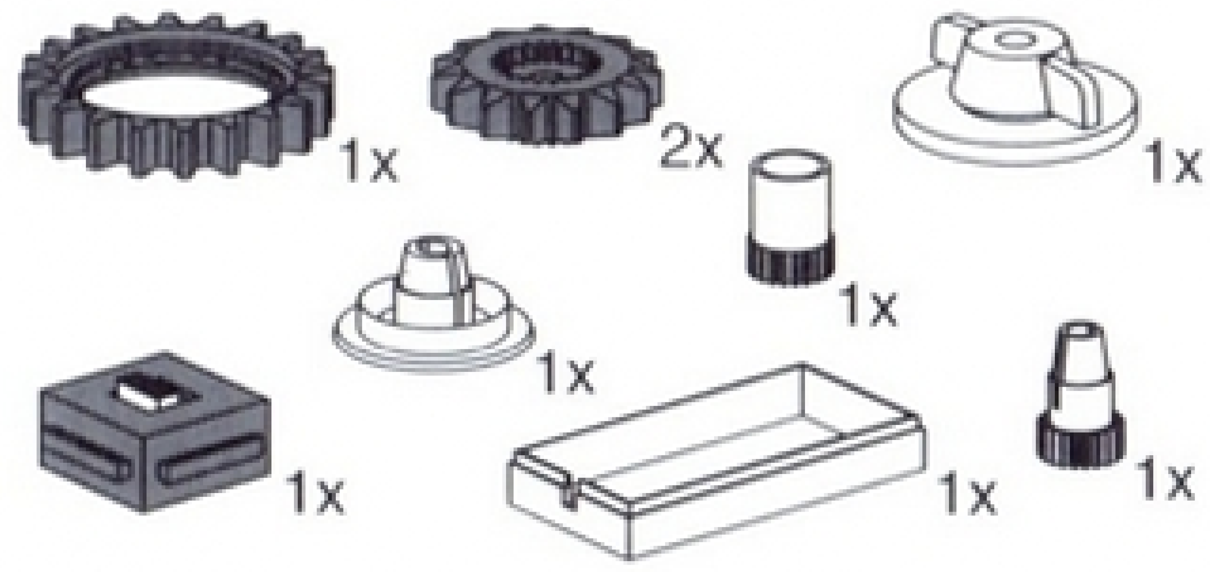
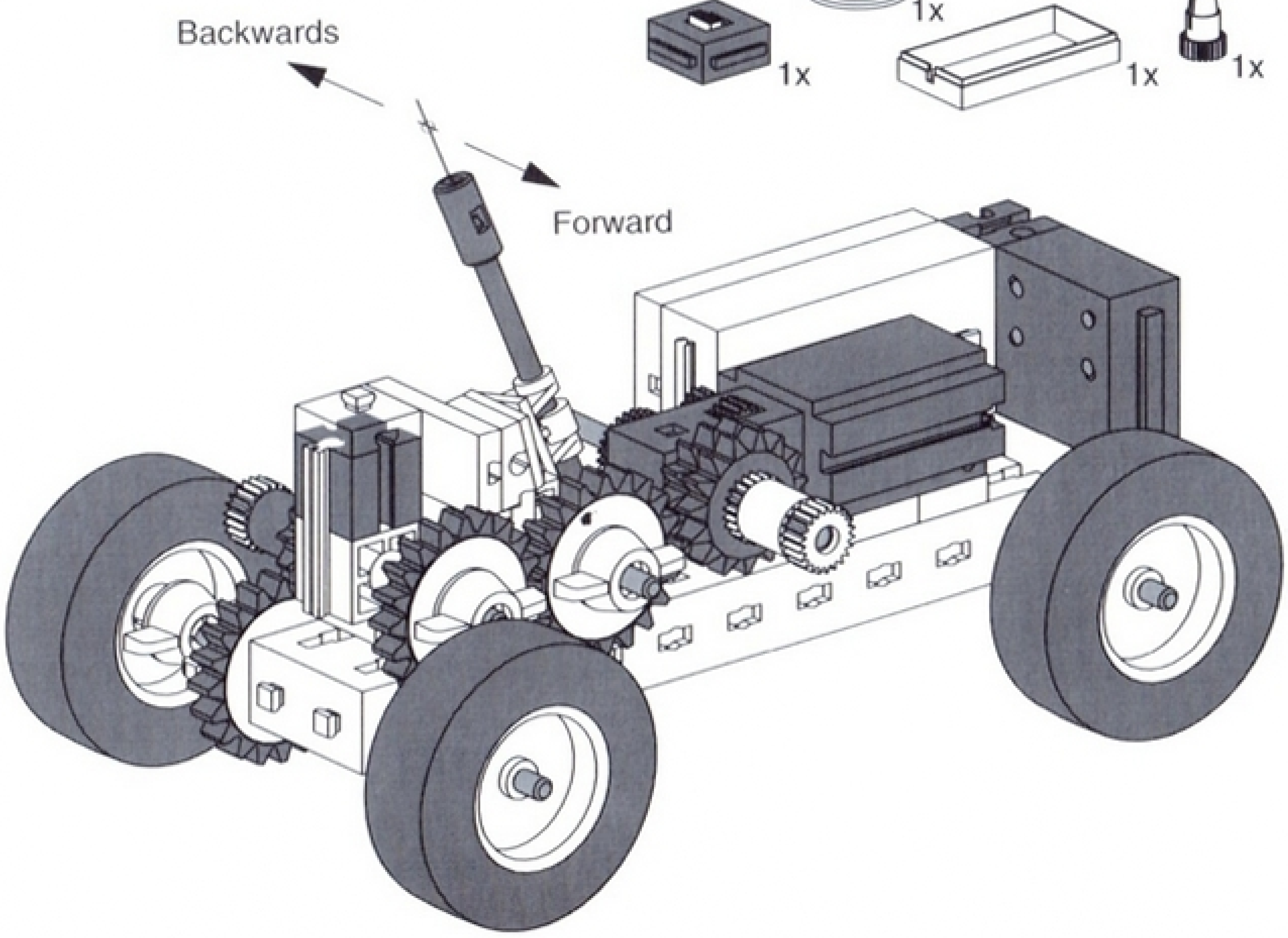
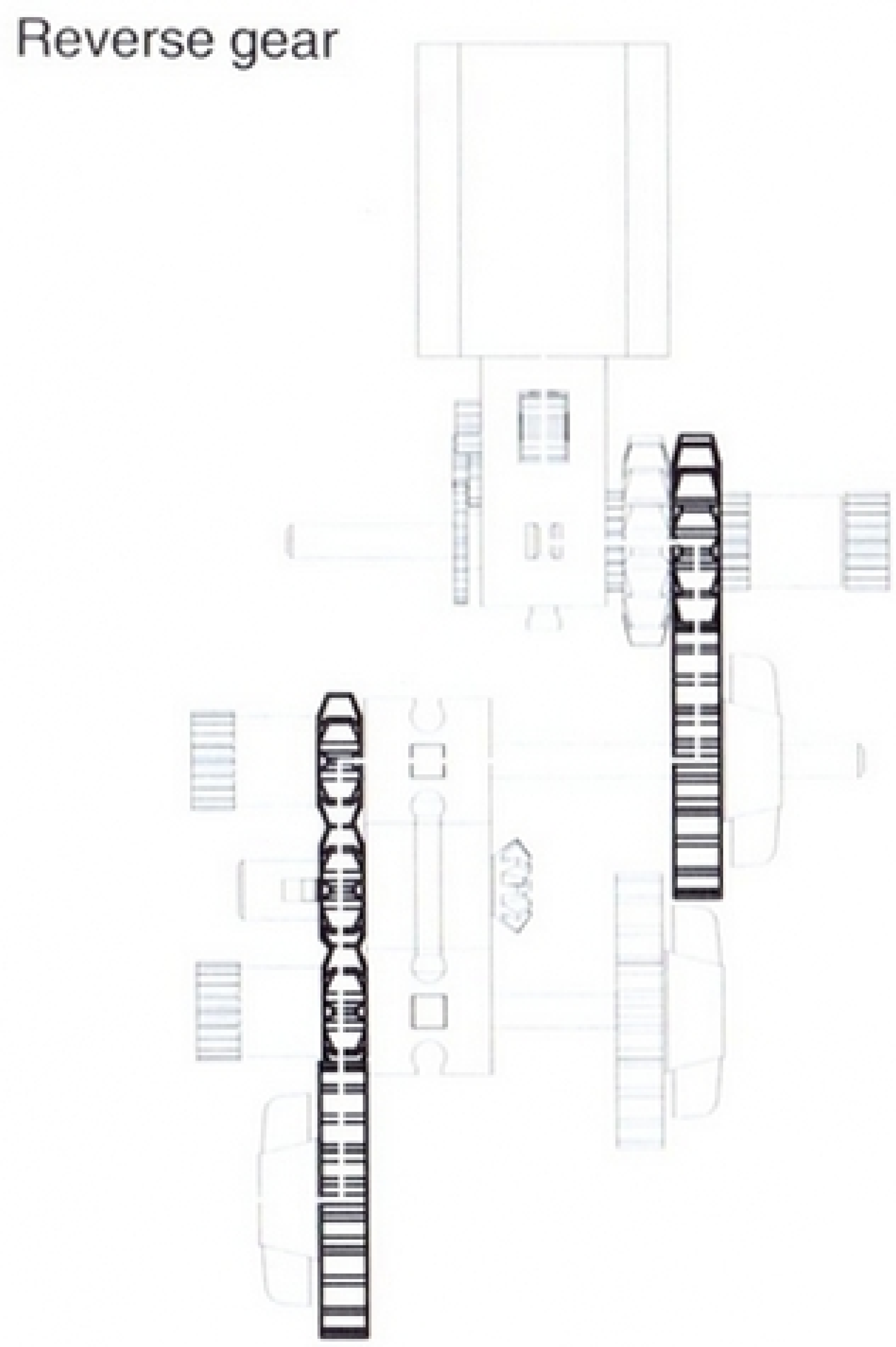
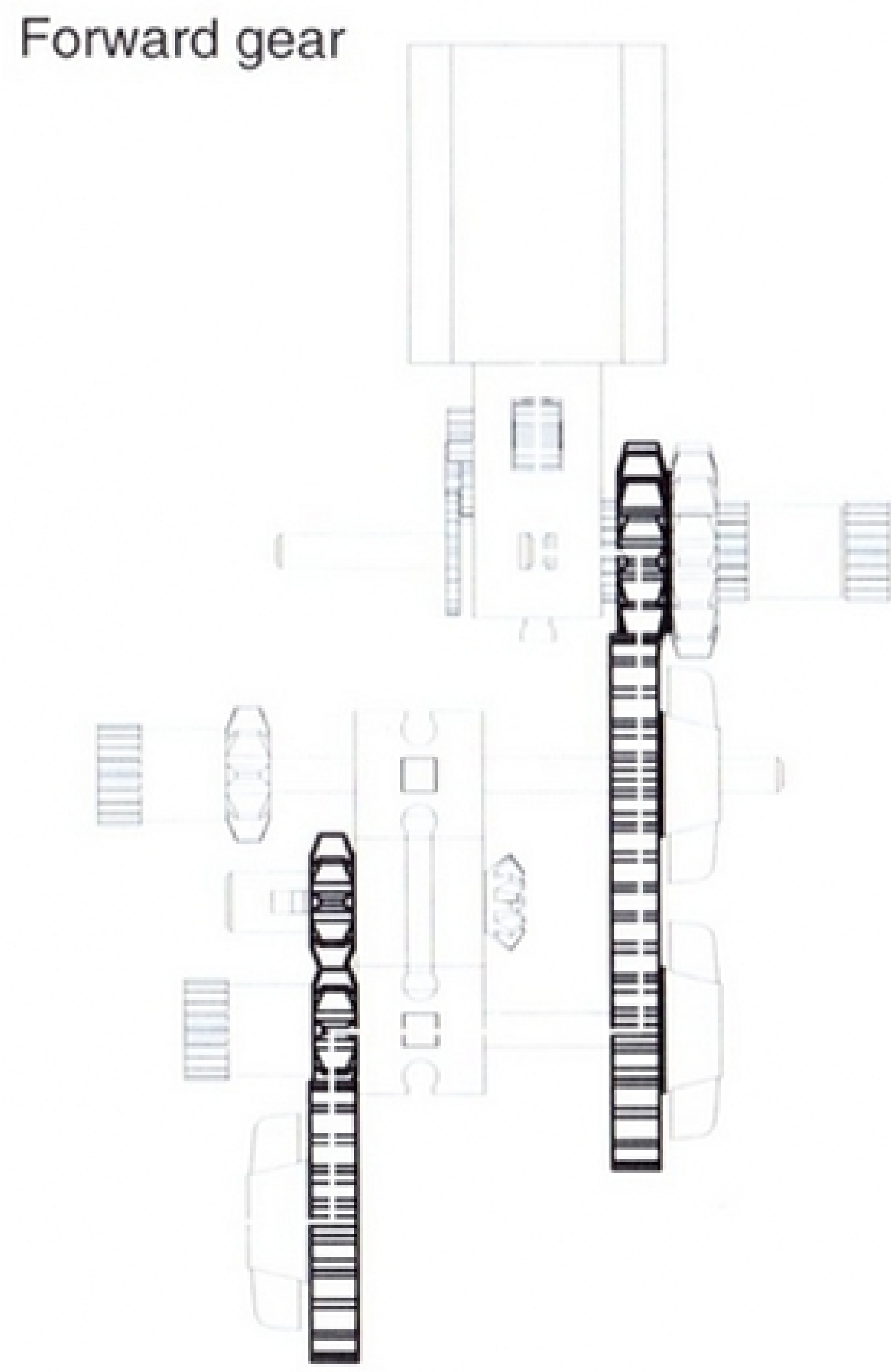

1x
2x
1x
1x
1x
1x
1x
1x


Backwards
Forward


Reverse gear


Forward gear

Vehicle with reverse gear and chain drive

The two gear speeds of the second vehicle with a reverse gear have different transmission ratios, because a real car does not travel as fast in reverse gear as in a forward gear. Once again, your vehicle has rear-wheel drive. If you look at the model from the back, the forward gear is engaged when the gear lever is pointing towards the right (if the model moves backwards instead, just reset the reversing switch to point in the other direction). (The various steps are shown on pages 54-55 of the German manual.)
This time the four gear wheels on the left-hand side of the vehicle are responsible for transmitting the power. What about the transmission ratio again (we always start with the motor shaft)?

20:10 x 15:20 x 20:15 = 6000:3000 = 2:1

In other words, the wheel turns half as fast as the motor shaft.
When the reverse gear is engaged (push the gear lever over to the left), the transmission ratio is rather different. Power is now transmitted via the gear wheels and the chain on the right-hand side of the vehicle. The chain transmission system means that the direction of rotation is reversed and the transmission ratio is now as follows:

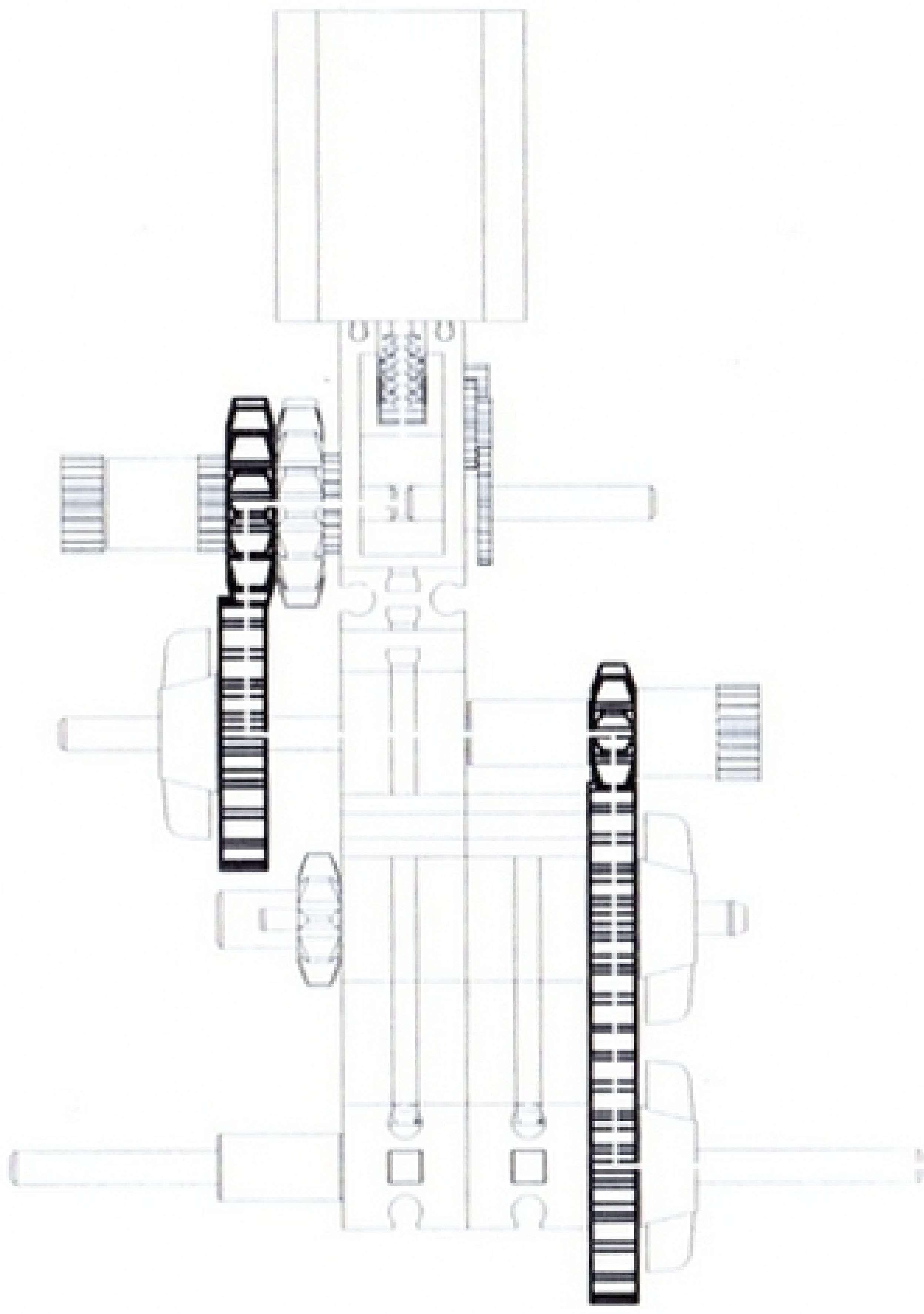
20:10 x 15:20 x 20:10 = 6000:2000 = 3:1

The motor shaft must now turn three times per wheel revolution instead of just twice - in other words the car travels more slowly in reverse.

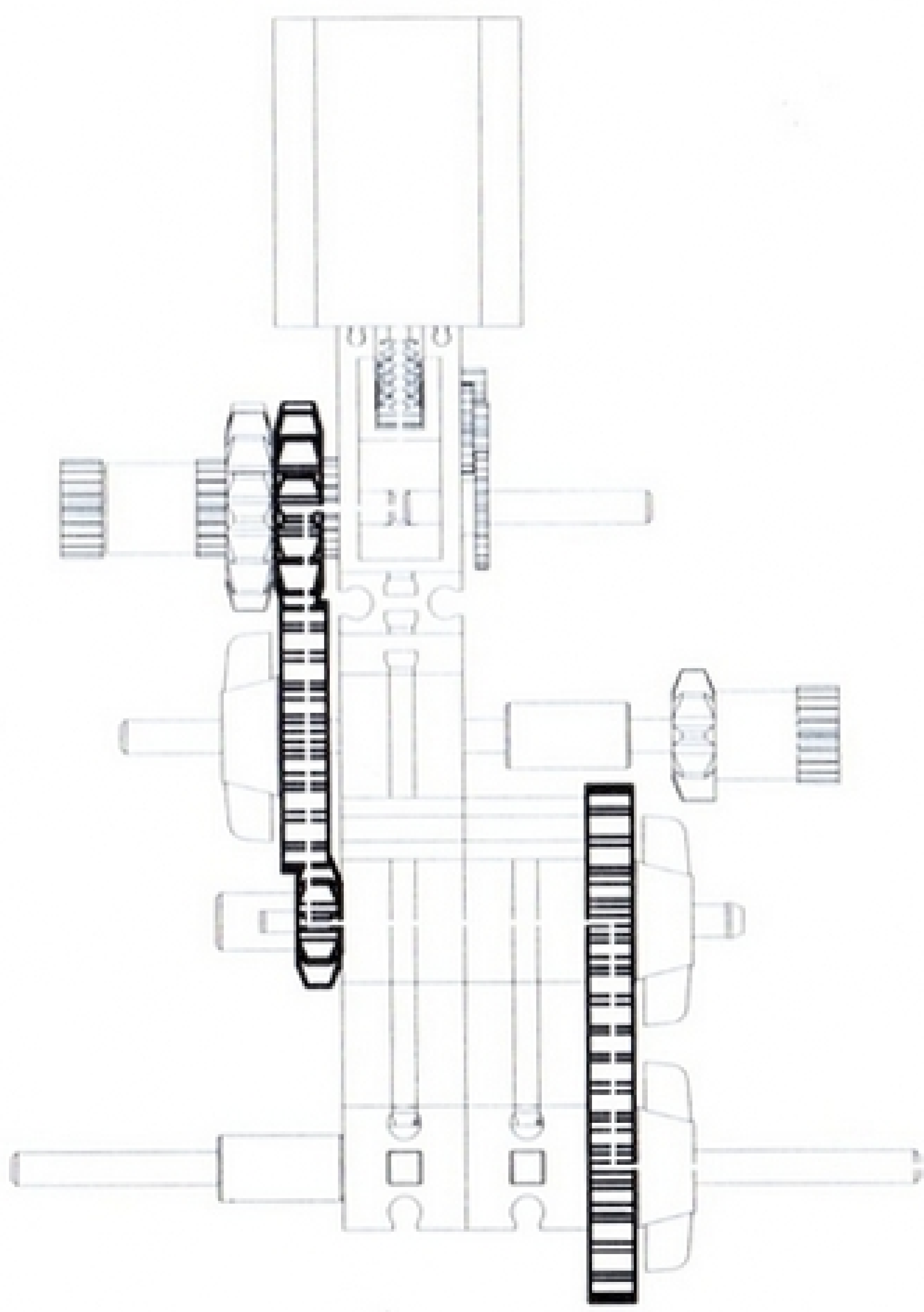
Vehicle with gearbox and steering

The last model in this section has two speeds again, the same as the very first models. It's probably best not to try and build it until you've read through the next chapter, since this time the front wheels have a steering system. The "gearbox" of this model is underneath the vehicle; it has been made as long and flat as possible. However, it works in exactly the same way as the gearbox with fast and slow speeds described earlier. (The various steps are shown on pages 57-58 of the German manual.)
This is a type of gearbox which is often found on trucks and lorries. If you also own a fischertechnik Master construction kit, you will be able to build a truck with a driver's cab and accessories.

Forward gear



Reverse gear



Vehicle steering systems

You have probably been wondering about the steering on the models you have built so far - after all, just driving straight ahead the whole time isn't terribly realistic. Even in olden days, carts and coaches always had some sort of steering system.

Vehicle with center-pivoted-axle steering

This very early type of steering system was extremely simple. The complete front axle was secured to a round wooden board, which was pivoted on the vehicle.

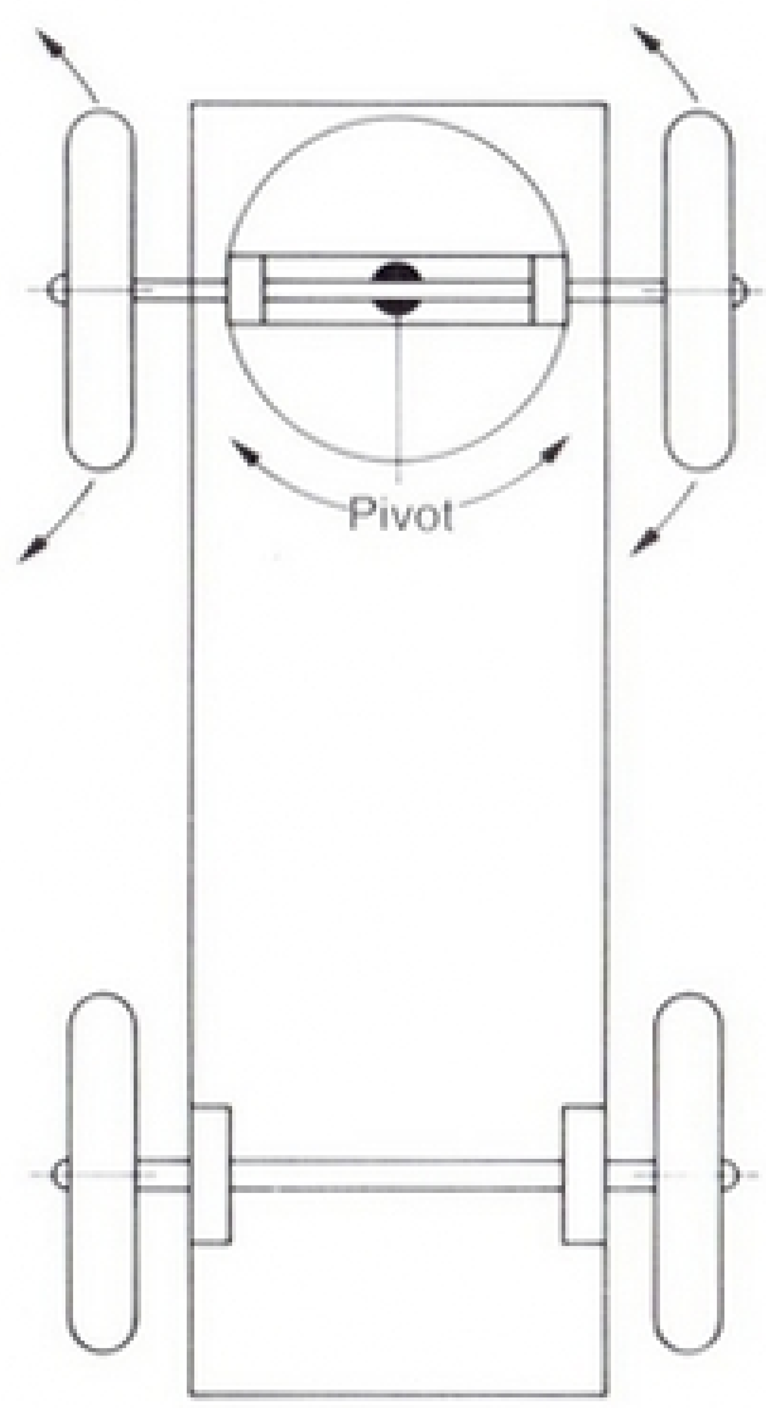


Fig. 22

The wheels have a rigid connection with the axle. Fig. 22 shows the construction from below. The complete front axle moves about the pivot in order to steer the vehicle.

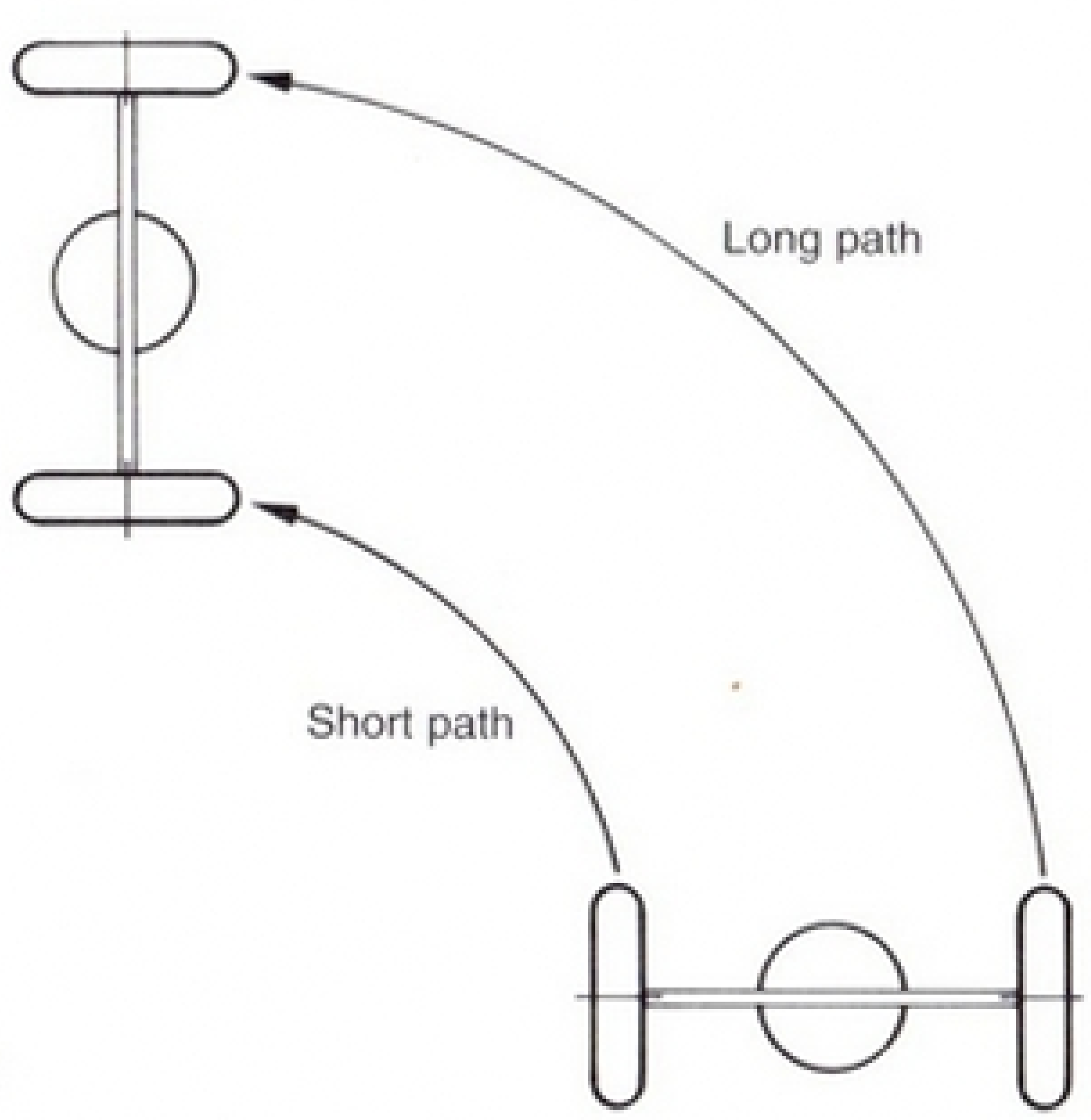


Fig. 23

However, it doesn't take long for the first problem to crop up, because as soon as you try and turn a corner, the wheels have to cover different distances. The wheel on the outside of the bend must travel farther than the wheel on the inside of the bend. Fig. 23 shows the two paths (you can only see the wheels on the front axle). You can try this out after you've built the first model if you want, by sticking a piece of adhesive tape on both wheels to mark them and then counting the number of revolutions of each wheel. How do you think we can solve this problem?
The answer is quite simple - the wheels must not be mounted rigidly on the axle, but must instead be allowed to turn on it. The wheel on the outside of the bend can then turn faster than the wheel on the inside of the bend (Fig. 24). This simple steering system, known as "center-pivoted-axle steering", was used for a long time in all vehicles, and you can still find it today in handcarts and trailers.

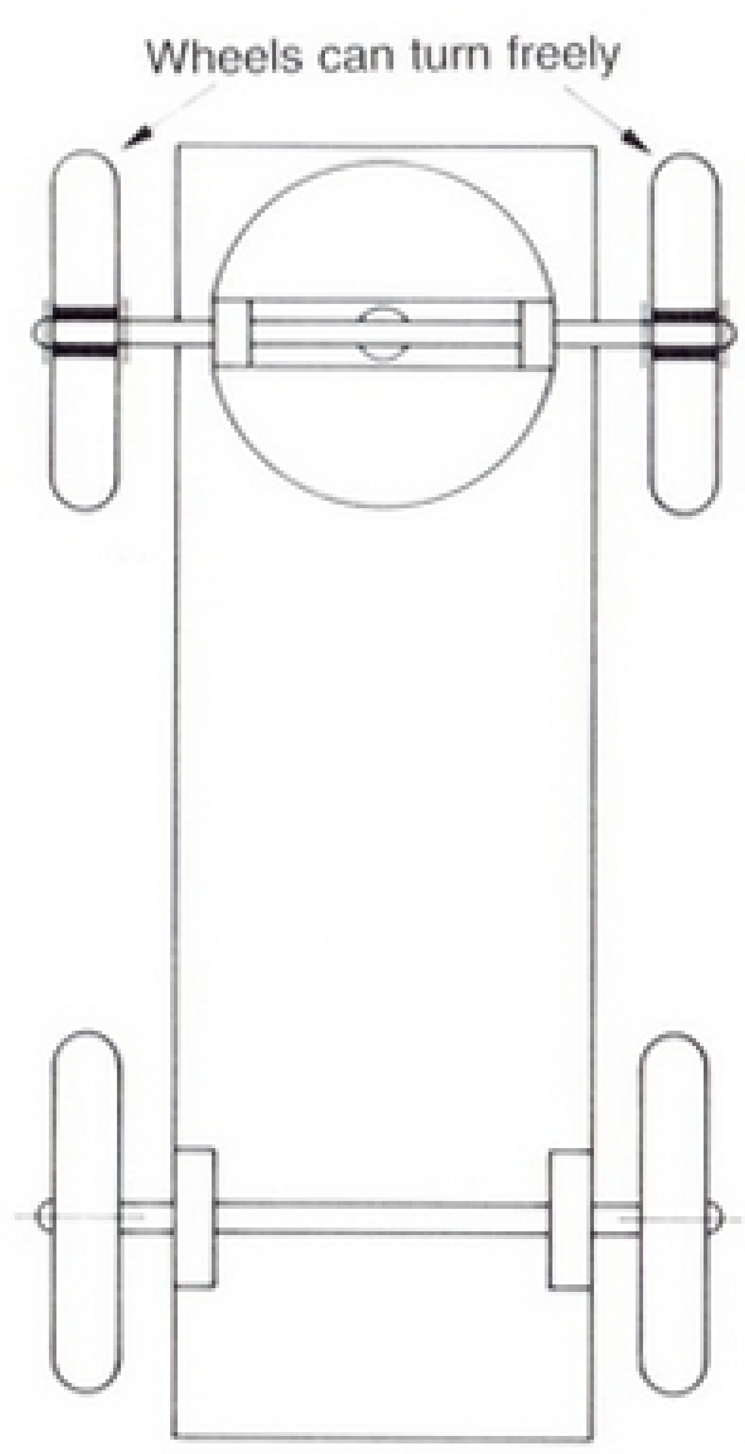


Fig. 24

A vehicle with center-pivoted-axle steering is extremely easy to build, and of course it also has a motor to drive it. The various steps are shown on pages 63-64 of the German manual.

One more problem left to solve!

The same principle obviously applies to the back wheels as to the front wheels. Once again, the wheel on the outside of the bend has to travel farther than the wheel on the inside. There is also a way round this however, as you will probably have noticed when you were building the model. Only one of the wheels (the one on the right-hand side of the vehicle) is actually driven. The left-hand wheel can turn freely, so that it is independent of the driven wheel. It is secured with a clip to stop it from sliding off the axle. This type of drive (transmission system) is often used in toy cars. If you want to drive both wheels instead, you must read the next chapter to find out how. But for now, back to the steering.

Vehicle with Ackermann steering

The center-pivoted-axle steering system has several other disadvantages, which you probably noticed when you were trying out your model. The wheels need an awful lot of room to turn, and the vehicle's stability is very poor when it has to take a tight bend - especially when it is travelling fast. Center-pivoted-axle steering was perfectly adequate for the very first cars, which were really no more than converted coaches and which weren't able to go particularly fast. As soon as engines became more powerful however, and cars faster, the car manufacturers were obliged to think up a better sort of steering system. This was how "Ackermann steering" came to be developed. The next model has this steering system, which is more complicated than the last one. The best thing is for you to build the model first, so that you can see how it works. The various steps are shown on pages 66-67 of the German manual.

How does it work?

The model allows you to appreciate the advantages of the new type of steering: the wheel base remains more or less constant, so that the stability and the lateral traction are extremely good, even in bends. In addition, the wheels need a lot less room to turn.
With the Ackermann steering system, each wheel is mounted on a very short axle, known as the "stub axle". The stub axle can be turned about the steering pivot pin or kingpin. As you have already seen on the model, this type of steering is more complicated - which is why we have simplified the model as compared with a "proper" steering system. How do you think this system manages to steer a car?
Take a look at Fig. 25, which is a view of the steering system from above. The steering parts are not shown the way they look in reality, but are schematic, so that it is easier for you to see how they work. There is a small gear system in the car between the steering wheel and the steering system, to allow you to steer more sensitively and with less expenditure of energy. The stub axle is turned clockwise or counterclockwise, together with the wheel, by means of the steering rod and the steering lever.
A sophisticated arrangement of levers and rods (track rod, track rod lever and the rigid section of the front axle) forms the "steering trapezium", which ensures that when you turn the wheels, the wheel on the inside of the bend is turned farther than the wheel on the outside, so that all the wheels (on both the front and rear axles) roll properly and without making a grinding noise. The extended diagram of the axles (Fig. 26) shows all the lines converging at the same point - the arcs travelled by the wheels thus all have the same center point, and this is what is important here.
The steering trapezium gets its name from the fact that the two track rod levers and the track rod form a trapezium with the front axle when the vehicle is travelling straight ahead, as shown in Fig. 25.

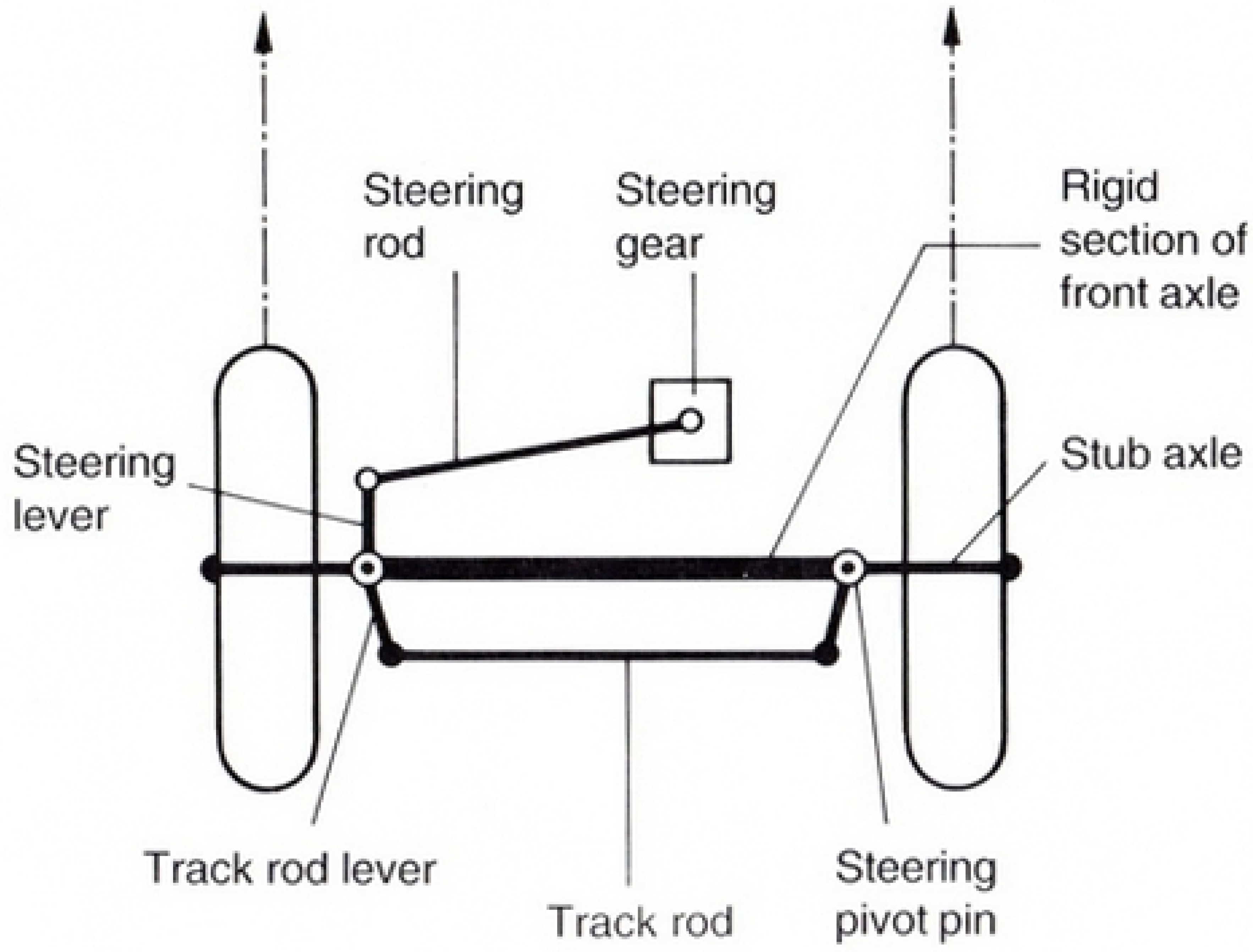


Fig. 25

When the vehicle takes a bend, the track rod is no longer parallel to the axle, and the paths at the ends of the two track rod levers are not the same length. The wheel on the inside of the bend is thus turned farther than the wheel on the outside (Fig. 27).
The steering system used for the fischertechnik model is not quite as complicated as this. The steering rod and the track rod are combined in one, and the steering trapezium has been displaced in front of the axle to allow the track rod lever and the steering lever to be combined as well. Now, after all that theory, it's about time we got onto building the next model.

Vehicle with four-wheel steering

Vehicles are sometimes required to be especially manoeuvrable (e.g. for moving earth on a building site where there is not much room), and even perfectly normal bends can be quite a major problem for very long vehicles (e.g. semi-trailers/articulated lorries). These types of vehicle are constructed so that both the front axle and the rear axle can be steered. A lot of manufacturers have also experimented with four-wheel steering for ordinary cars, to make it easier to park into a space. Special vehicles, such as overlong heavy-duty vehicles, sometimes even have a separate driver's cab at the rear, from which the back wheels can be steered. In this four-wheel steering model, the steering system for the rear axle has been coupled to the front axle, and both axles are steered using the same steering wheel. The various steps are shown on page 71 of the German manual.
If you also own the fischertechnik Master construction kit, you will be able to build the model with a superstructure (driver's cab and loading area), so as to obtain a realistic truck with four-wheel drive (Fig. 28).

Vehicle transmission systems

We were obliged to restrict the transmission systems of the steerable models to just one wheel in order to improve the cornering ability, though of course this caused the driving power to be reduced at the same time. Nor are transmission systems which work via a chain or directly via gear wheels used in modern cars. The majority of cars and almost all types of truck have the engine at the front, and yet the back wheels are the ones which are driven. This chapter tells you how the motive force is transferred to the back wheels and how the two back wheels can be driven.

Vehicle with drive shaft and bevel-gear drive

The first model with a drive shaft is a typical type of truck (the various steps are shown on pages 75-77 of the German manual). The motor (engine) is at the front underneath the driver's cab; its power is transferred to the back wheel via a drive shaft. The drive shaft leads lengthways underneath the truck to the rear. In order to transfer the power of the motor to the shaft, and then from the shaft to the wheel, the motive force must be diverted at right angles. "Bevel gears" are used to do so. "Bevelled" means that the gear wheels are at an angle.

You will see how they work when you build the model. You can of course work out the transmission ratio of the bevel gears in the same way as with straight gear wheels.

The rear axle of a real car has a suspension system. If the axle moves up and down, you can't make the drive shaft rigid. Joints must be incorporated in the drive shaft so that it can still be moved (Fig. 29). The joints are known as "universal joints" or "cardan joints" and the drive shaft accordingly as the "universally jointed shaft" or "cardan shaft", even though other types of joint are used nowadays for it as well. If you take a look underneath your own car, you will see universal joints on the driving wheels.

This construction kit also contains a universal joint; we shall need it in the next chapter for the last model of all, which has four-wheel drive.

Vehicle with differential

Both the rear wheels are driven on this model. Do you still remember how the two wheels on the rear axle behaved in a bend? The wheel on the inside of the bend must turn slower than the wheel on the outside. A so-called "differential" is mounted between the drive shaft and the wheels in order to achieve this.

The differential distributes the rotation of the drive shaft between the two wheels in different amounts. Build the model first however, before we go into the way the differential works in more detail (the various steps are shown on pages 79-80 of the German manual).

Building a model with MASTER components

You can add extra parts to the previous truck model if you own other fischertechnik construction kits (e.g. Master). The drawings on page 81 of the German manual will give you a few ideas.

Demonstration model of a differential

If you build this demonstration model with your fischertechnik components, you will be able to understand better how the differential works (the various steps are shown on page 83 of the German manual).

How does it work?

The demonstration model lets you study all the things that are going on in more detail. Start by turning one of the wheels. What happens? The other wheel turns in the opposite direction. Then switch on the motor. The two wheels should now turn at the same speed. If you stop one of the wheels with your hand, the other wheel will carry on turning; in fact it will rotate even faster. This is the reason why a real car refuses to move if one of its wheels spins (e.g. on ice).
Fig. 30 is a drawing of a differential which has been cut open. The differential casing is rigidly connected to the crown wheel. Power is transmitted to the two wheels via the differential gears, which compensate the difference in speed between the car wheels on the inside and outside of the bend. They rotate about their own axes and roll off on the axle-drive bevel gears.

If the car is moving straight ahead, the differential gears don't turn, but instead form a rigid connection between the two half shafts. When the inside wheel is braked slightly as the car goes round a bend, the differential gears begin to turn and make the wheel on the outside of the bend faster. Overall, the wheel on the outside of the bend always turns faster than the drive shaft by the same amount as the wheel on the inside of the bend is slower. The table below shows how the different gears turn inevery possible combination.

Crown wheel	Left-hand axle-drive bevel gear	Right-hand axle-drive bevel gear
1 revolution	1 forward revolution	1 forward revolution
1 revolution	1/2 forward revolution	1 1/2 forward revolutions
1 revolution	1 1/2 forward revolutions	1/2 forward revolution
1 revolution	No movement	2 forward revolutions
No movement	1 forward revolution	1 backward revolution
No movement	1 backward revolution	1 forward revolution

Vehicle with rear motor and differential

The differential can also be driven via the spur gear (opposite the crown wheel) - in this case it works exactly the same as when driven via the bevel gear (Fig. 31). The motor of the last model in this chapter is at the rear (like the engine in most cars); it can therefore be linked directly to the differential. You will probably find it very easy to build, providing you follow the steps shown on pages 86-87.

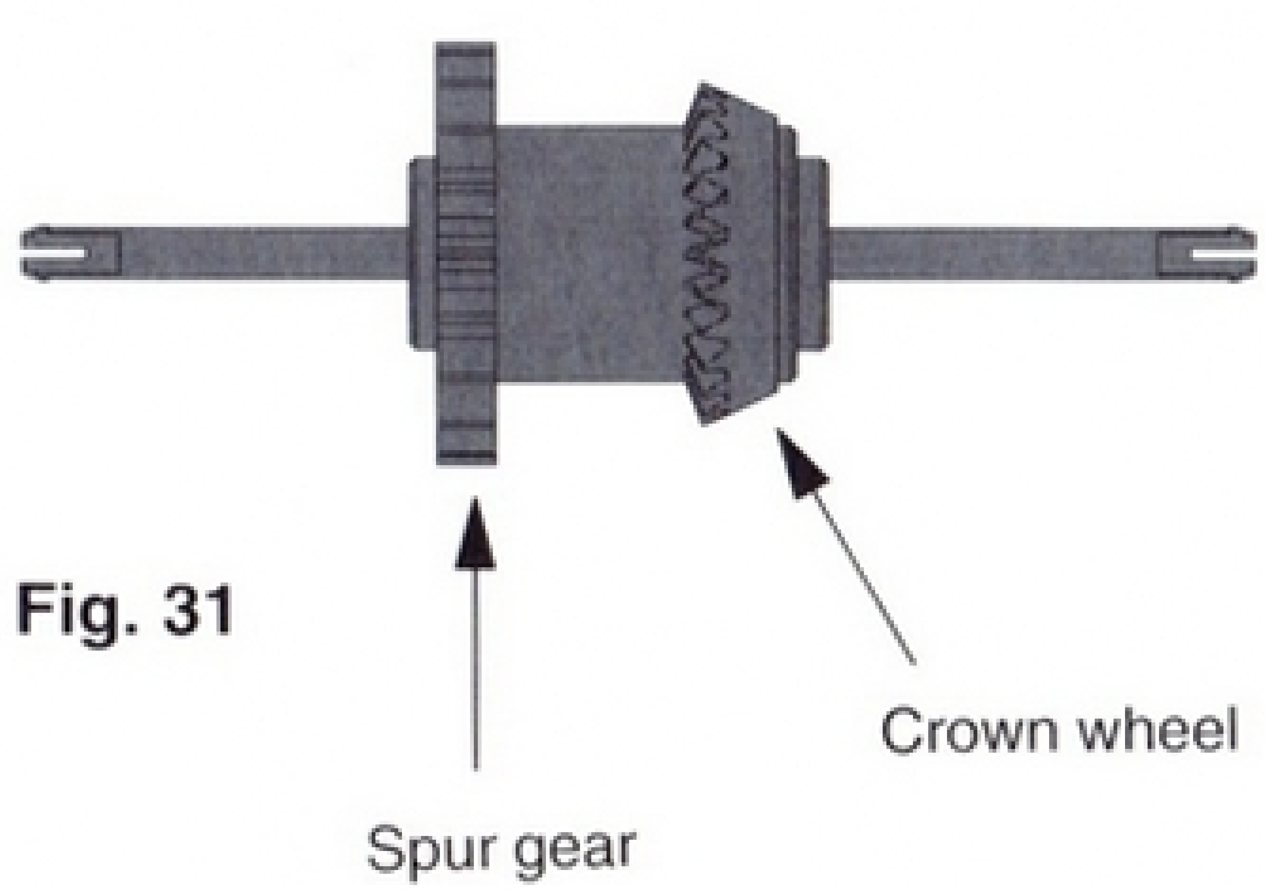


Fig. 31

Vehicle with swing axle and differential

A vehicle must come up to different standards if it is to be driven off the road. All the wheels must always be touching the ground, so that the car does not tip over and so that the driving wheels can always grip. There are various design principles which can be applied to achieve this, e.g.:

> The axles are no longer rigidly connected to the vehicle, but are pivoted about the drive shaft (swing axle).

> The wheels on both axles are driven (four-wheel drive), so that the vehicle can cope with slippery terrain.

These two alternatives can be used either individually or in combination.
You can often find a swing axle on trucks which are used on building sites. The next model is of a vehicle with a swing axle for the back wheels (the various steps are shown on pages 89-91 of the German manual).

Vehicle with four-wheel drive and articulated-frame steering

Many cars, off-road vehicles and construction vehicles are driven with both axles, and thus with all four wheels. The last model in this kit (see page 94 of the German manual) has two driven axles. However, only one wheel is driven on each axle, so that the vehicle can also go round bends. The steering system is different from that used for the previous models; it is a type used in construction vehicles and is known as "articulated-frame steering".

Parts list for illustrations and article numbers

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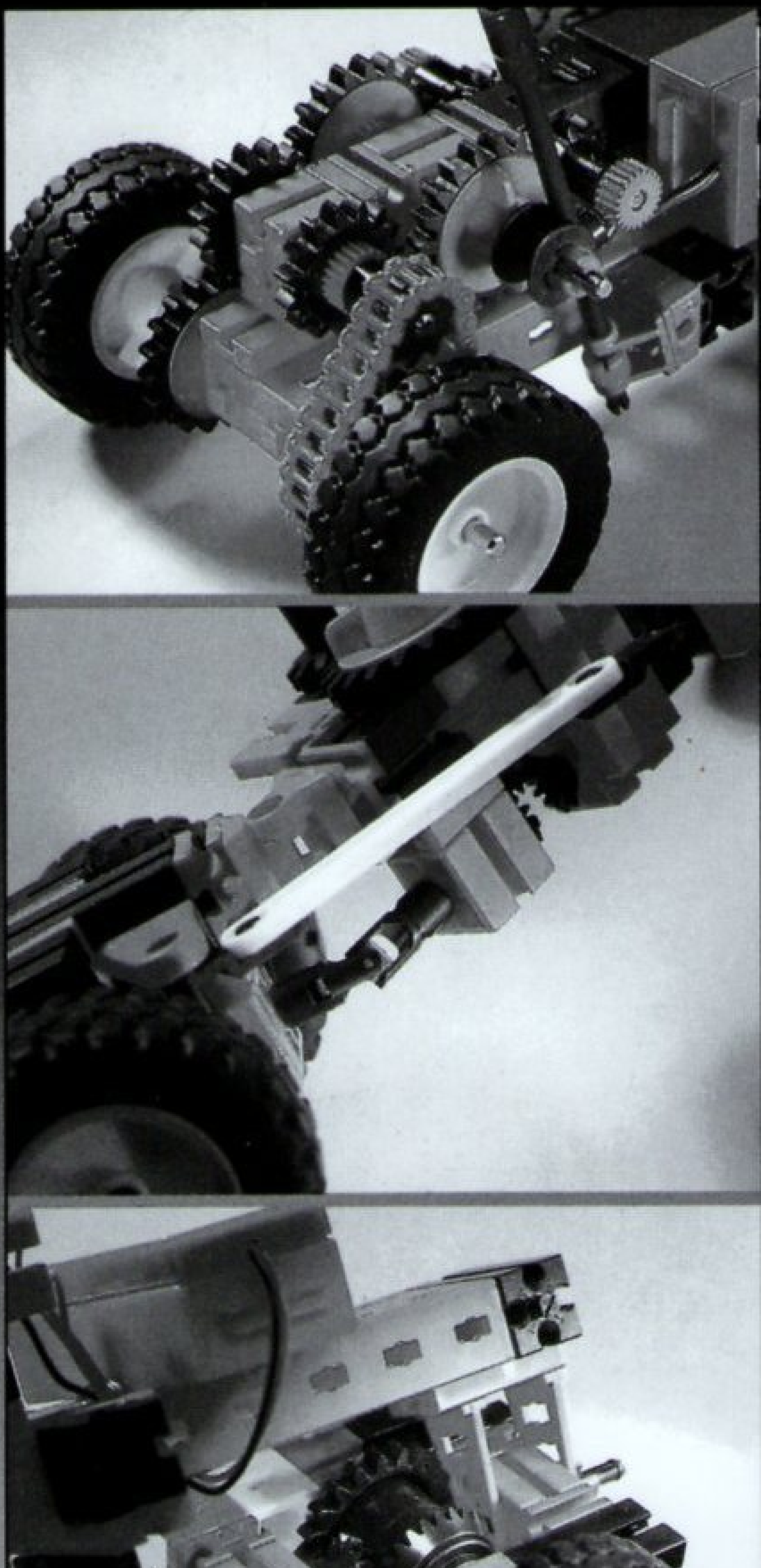

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