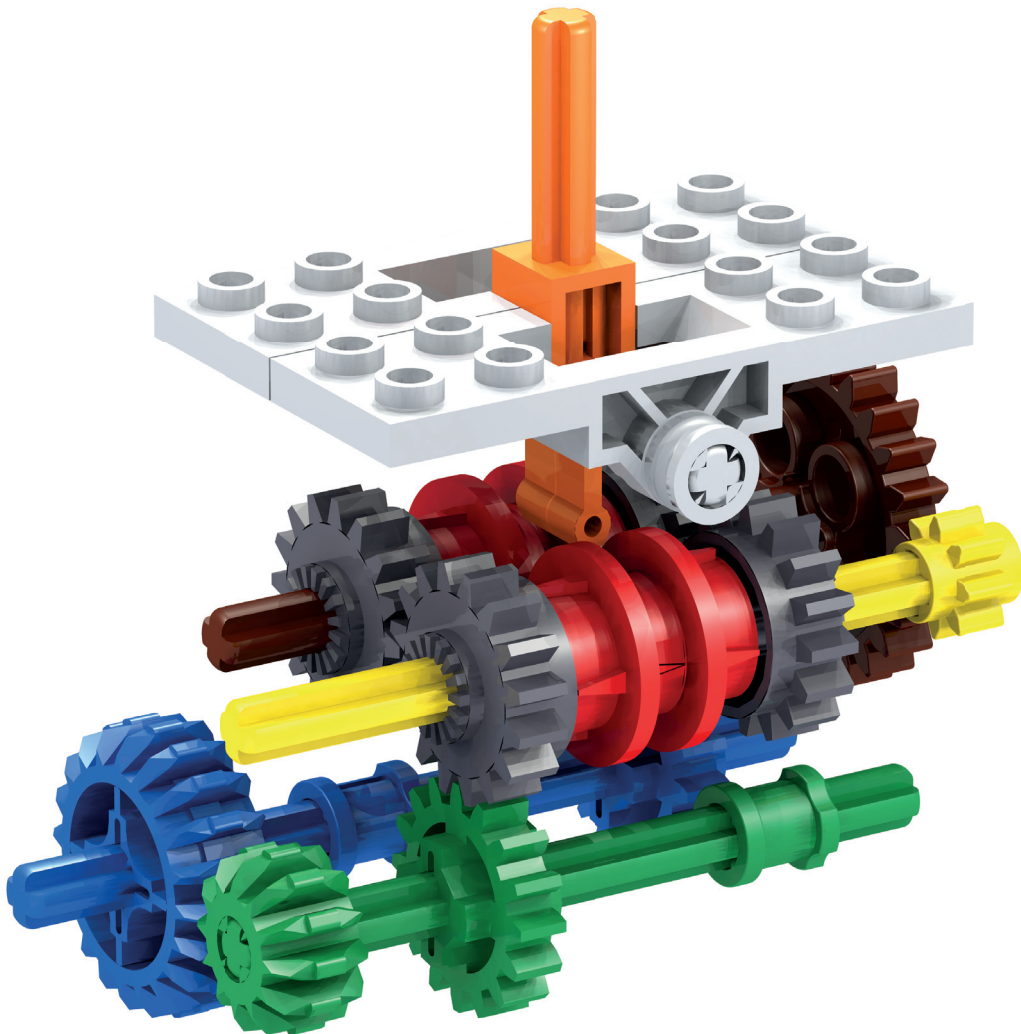




# THE UNOFFICIAL LEGO® TECHNIC BUILDER'S GUIDE

Paweł "Sariel" Kmieć



# index

**NOTE** Italicized page numbers refer to illustrations.

## Numbers

- 2L axle, 32
- 2-speed transmissions
  - linear heavy-duty, 254, 262-264
  - orbital, 255
  - ratchet, 256, 267
  - RC motor, 255, 264-265
  - synchronized, 254
- 3L axle, 32, 33
- 3-speed linear transmission, 256, 268-269
- 4×4 (four-by-four), 7, 47
- 4-bar linkage, 69-70
- 4L axle, 32, 33
- 4-speed transmissions, 257-258, 270-271
- 4WD (four-wheel drive), 7
- 4.5 volt motors, 163
- 5L axle, 32
- 5-speed linear transmission, 258
- 5.5L axle with stop, 33
- 6L axle, 32
- 6L cylinder, 107
- 7L axle, 32
- 8L axle, 32, 33
- 8-tooth gear, 49, 58
- 9 volt motors, 163-170
- 9L axle, 32
- 10L axle, 32
- 10-speed synchronized transmission,
  - 259, 271-275
- 12L axle, 32
- 12-tooth gear, 50
- 14-tooth gear, 50
- 16/24-tooth differential gear, 53
- 16L axle, 32
- 16-tooth gear, 50-51
- 24-tooth gear, 52, 53, 58
- 32L axle, 32
- 36-tooth gear, 53
- 40-tooth gear, 53, 120
- 1969 Dodge Charger, 295
- 2838 motor, 164-165
- 8041 set, 151
- 8043 Motorized Excavator set, 25
- 8048 Buggy set, 25
- 8070 Super Car set, 24, 34
- 8262 Quad-Bike set, 25
- 8263 Snow Groomer set, 25
- 8265 Crane Truck set, 70
- 8275 set, 242
- 8285 Crane Truck set, 25
- 8288 Crawler Crane set, 154
- 8296 set, 297
- 8421 Mobile Crane set, 25
- 8422 set, 299
- 8436 Truck set, 30
- 8448 Super Street Sensation set, 24
- 8460 Pneumatic Crane Truck set, 71
- 8466 4×4 Off-Roader set, 24
- 8480 Space Shuttle set, 24
- 8485 Control Center II set, 302
- 8850 Jeep set, 24
- 8855 Prop Plane set, 303
- 8865 set, 197
- 8880 set, 197
- 43362 motor, 165
- 47154 motor, 166
- 53983 turbine, 319
- 71427 motor, 165

## A

- AAA battery box, 174
- AA battery box, 174
- Ackermann steering geometry, 195-198
- actuators. See linear actuators
- adapter plugs, 186
- adders, 277-280
- aging of LEGO pieces, 159-160
- air deflectors, 296-297
- air pressure, 112
- aircraft, 302-305
- airtanks, 111
  - and automated pressure switch, 123
  - non-LEGO, 112
- all-wheel drive (AWD), 7

- arches, 34
- arctangent (inverse tangent), 202
- arms of levers, 67
- automated pressure switch, 123-124
- autovalve, 120-122
- AWD (all-wheel drive), 7
- axle joiner, 252
- axle joint, hose connector with, 110
- axle pins, 11
  - in linear clutches, 83, 84
  - with towball, 12
- axles, 31-34
  - categories of, 32
  - convergence of, 199-202
  - with differential lock, 81
  - driven, 203
  - driven and suspended, 209-224
    - pendular suspension with turntables, 210-213
    - portal axles (geared hubs), 213-217
  - flexible, 23, 32, 34
  - holes for, 10
  - independent, 227-229
  - independent steered, 226-227
  - modified, 33
  - pendular portal
    - heavy duty, 230-235
    - with worm gear, 236-240
  - pendular steered, 225
  - standard, 32
  - with stops, 33
  - structural reinforcement with, 31
  - supporting, 140-144
  - transferring drive with, 31

## B

- back iron, 49
- backlash, 5
  - with 8-tooth gear, 49
  - avoiding, using pneumatics, 47
  - between driving ring and gear, 253
  - and delay in motion, 5
  - from pendular axle with worm gear, 236

- ball joint, 38–39
  - balloon tires, 317
  - balls, 55
  - batteries, 174–175
  - battery boxes, 171, 174
  - beams, 12–14
    - aligning bricks with, 13
    - connecting to bricks, 27–28
    - in eccentric mechanisms, 85
    - height-to-width ratio for, 13
    - orientation independent of, 13
    - reinforcing parts using, 138, 141
    - versatility of, 13
  - bevel gears, 48
  - blueprints, 307–314
    - dimensions in, 309–314
    - finding online, 307–308
    - using photos instead of, 308
  - BMR-2 personnel carrier, 322
  - body frames, 151–153
  - Boeing CH-47 Chinook helicopter, 303
  - bogies, 246–247
  - booms, on cranes, 49, 69–71, 154
  - brackets
    - for cylinders, 110–111
    - for linear actuators, 184
  - bricks, 9–10
    - aligning with beams, 13
    - connecting to beams, 27–28
    - height of, 9
    - height-to-width ratio for, 13
    - holes in, 10
    - with lights, 91
    - Technic vs. regular, 18
    - with two plates, 19
  - Brown truss, 155–156
  - buggies, 8, 25, 297
  - builder showcase, 135
  - bushes, 35–38
    - connecting modules using, 37
    - half, 35–37
    - with long pin, 37–38
    - regular, 37
- C**
- cab-over-engine trucks, 296–298
  - cams, 124, 130
  - Cardan joints. *See* universal joints
  - cars, 295–296
    - 1969 Dodge Charger, 295
    - 8070 Super Car set, 24, 34
    - 8448 Super Street Sensation set, 24
    - Dodge Viper, 296, 311
    - Ford GT40, 23, 26
    - Pagani Zonda, 296, 307
  - casings, reinforcing
    - differential, 144–148, 203
    - worm gear, 149–150
  - catapult, 83
  - catch, transmission changeover, 80, 252–253
  - center of gravity, 7
  - center of turning radius, 199
  - chains, 57–59
  - changeover catch, 80, 252–253
  - channel selector, 173
  - chassis, 151–153
  - Chebyshev linkage, 73
  - chromed pieces, 320
  - circular elements, 316–319
  - clearance from ground, 7, 8, 205
  - clutches, 83–84, 185
  - colors, 319–320
  - compressors, 113, 115–119. *See also* autovalve
  - connector pieces, 321, 322
  - constant ground clearance, 205
  - continuous rotary motion, 89
  - continuously variable transmissions (CVTs), 260, 276
  - control module, 103
  - convergence of axles, 199–202
  - counterjib, 158–159
  - coupling motors, 277–280
  - couplings, 87–88
  - cranes
    - 8285 Crane Truck set, 25
    - 8288 Crawler Crane set, 154
    - 8421 Mobile Crane set, 25
    - 8460 Pneumatic Crane Truck set, 71
    - body frame of, 153
    - booms on, 49, 69–71, 154
    - levers on, 71
    - Liebherr LTM1200 mobile telescopic crane, 310
    - string and pulley systems on, 61–62
    - tower cranes, 154, 158–159
  - crank mechanisms. *See* eccentric mechanisms
  - cruciform, defined, 38
  - C-shaped frames, 144
  - curb-to-curb turning radius, 6
  - custom mechanical solutions. *See* mechanical solutions, custom
  - custom-chroming, 320
  - CVTs (continuously variable transmissions), 260, 276
  - cylinders, 103
    - 6L cylinder, 107
    - bracket for, 110–111
    - large, 107
    - in New LEGO pneumatic system, 104, 105, 108
    - in Old LEGO pneumatic system, 103, 104, 107
    - in pneumatic engines, 124–134
      - single-cylinder, 125–127
      - two-cylinder, 128–134
    - small, 108
- D**
- dead gears, 251
  - dead spots, in pneumatic engines, 124
  - delay in motion, and backlash, 5
  - Demag H135 model, 324
  - dependent suspension, 204
  - details, 320–323
  - differential casings, 144–148, 203
  - differential gears, 53–54
  - differential locks, 78–82
  - differential mechanism, 44, 77–78
  - differential pulley system, 63–65
  - dimensions, in blueprints, 309–314
  - distribution block, 103, 104, 106
  - distribution transmissions, 260–276
  - Dodge Charger, 295
  - Dodge Tomahawk concept motorcycle, 300
  - Dodge Viper, 296, 311
  - double tackle, 64
  - double-axle turntable transmission, 96–100
  - double-beveled gears, 50, 51, 251–252
  - double-wishbone independent suspension, 206–207
  - drifting, tires for, 4

drive  
transferring to linear actuator, 184, 185  
transmitting through turntable, 96–100  
driveline, 6  
driven and suspended axles, 209–224  
pendular suspension with turntables, 210–213  
portal axles (geared hubs), 213–217  
driven axles, 203  
driver gears, 44–45, 48  
driveshaft, 6  
drivetrain, 6  
driving rings, 252–254

## E

E motor, Power Functions, 167  
eccentric mechanisms, 84–85  
efficiency, 5  
of gears, 46  
of pneumatic engines, 130  
and size/weight of parts, 5  
effort, of levers, 67  
European trucks, 296–298  
even and odd width, 30  
excavator, 25  
extendable driveshaft section, 6  
extension driving rings, 253, 254  
extension wires, 186–187

## F

fantails, 303  
flashing lights, 91–92  
flexible axles, 23, 32, 34  
floating axle (trailing arm) suspension, 209, 222–224, 248–249  
flotation, 244  
FLU (fundamental LEGO unit), 9  
fluids, in pneumatic systems, 113  
flywheels, in pneumatic engines, 125  
follower gear, 44, 48  
Ford GT40, 23, 26  
form vs. function, 295–305  
aircraft, 302–305  
cars, 295–296  
motorcycles, 299  
tracked vehicles, 299–301  
trucks, 296–299  
four-by-four (4×4), 7, 47  
four-wheel drive (4WD), 7

frames, 151–153  
friction, 4  
friction pin, 11  
front loader, 70  
front-wheel drive (FWD), 7  
fulcrums  
of levers, 67–69  
of suspension systems, 204  
function. *See* form vs. function  
fundamental LEGO unit (FLU), 9  
FWD (front-wheel drive), 7

## G

gear ratios, 45–46, 58–59  
in transmissions, 251  
when using adders, 279  
gearboxes, 143, 149  
geared hubs (portal axles), 213–217, 318  
gearing down, 43, 46, 48–49  
gearing up, 43, 46  
gears, 43–56  
acceleration of, 46  
backlash of, 47  
controlling rotational direction, 47–48  
efficiency of, 46  
hard-coupling Power Functions  
switches with, 92–93  
reduction of, 46  
reinforcing  
differential casings, 144–148  
perpendicular gears, 142, 143  
by supporting axles, 140–144  
where to reinforce, 138–140  
worm gear casings, 149–150  
transforming speed or torque with, 43  
in transmissions  
dead, 251  
double-beveled gears, 251–252  
engaging of, 251–253  
reverse gear, 254  
types of. *See also* worm gears  
8-tooth, 49, 58  
12-tooth, 50  
14-tooth, 50  
16-tooth, 50  
16-tooth with clutch, 50–51  
20-tooth, 51  
24-tooth, 52, 58  
24-tooth with clutch, 52

24-tooth with crown, 55  
36-tooth, 53  
40-tooth, 53  
differential, 53–54  
double-bevel 12-tooth, 50  
double-bevel 20-tooth, 51  
driver, 44–45  
follower, 44  
Hailfire Droid wheel, 55  
idler, 44–45, 59  
knob wheel, 55  
obsolete, 56  
planet, 278  
single-bevel 20-tooth, 51  
single-bevel 20-tooth with  
pin hole, 51  
spider, 278  
turntables, 54–55  
used with chains, 58  
wear of, 160

Geneva mechanisms, 89–90  
GIMP application, 310  
gravity  
center of, 7  
and ratchets, 83  
grease, 4  
grip, defined, 4  
ground clearance, 7, 8, 205  
gun tackle, 63  
gyn tackle, 64

## H

Hagglunds BV 206 personnel carrier, 300  
Hailfire Droid wheel gear, 55  
half bush  
smooth, with cutout, 37  
thickness of, 60  
toothed, 35–36  
toothed, with cutout, 36  
variants of, 35  
half pins, 11, 12  
half studs, 14–15  
half-track truck, 301  
hard plastic tracks, 242–244  
hard-coupling motors, 277, 280  
height, of bricks and plates, 9  
height-to-width ratio, 13  
helicopters, 302–305  
high torque, joints for, 38

hockey spring, 195  
 Hoeken's linkage, 73  
 holes in bricks, 10  
 hoses
 

- connecting, 110
- non-LEGO, 112
- pneumatic, 108–109
- splitting, 110
- use of term, 109

 hubs, 305  
 Humvee, 26, 312  
 hydraulic system, turning pneumatic system into, 113

**I**

idler gears, 44–45, 59  
 independent axle, 226–229  
 independent suspension, 220–221
 

- defined, 204
- double-wishbone, 206–207

 input axle, 44  
 interacting gears, 45  
 intermittent rotary motion, 89  
 inverse tangent (arctangent), 202  
 inversely proportional, speed and torque as, 44

**J**

Jeep Wrangler Rubicon, 297  
 jib, 158–159  
 joints, universal. *See* universal joints  
 jumper plates, 15

**K**

Kenworth Road Train model, 18  
 knob wheels, 55, 203  
 knobs
 

- hard-coupling with, 280
- wear of, 160

**L**

L motor, Power Functions, 168  
 large cylinder, 107  
 LEDs, 91–92, 187–188  
 LEGO pneumatic engine (LPE), 124–134  
 Leopard 2A4 tank, 301, 323  
 levers, 67–71
 

- classes of, 68–69
- effort of, 67

fulcrums of, 67–69  
 law of the lever, 67  
 and linkages, 69–71  
 load of, 67, 70  
 mechanical advantage of, 72  
 parallel, 70, 71  
 remotes with, 179–180

Liebherr LTM1200 mobile telescopic crane, 310  
 Liebherr R944C, 243  
 liftarms, 12  
 lights
 

- flashing, 91–92
- reverse, 90–91
- turn signals, 92–95

 linear (sequential) transmissions, 252  
 linear actuators, 183–186
 

- flawed, 184–185
- large, 183–185
- vs. pneumatics, 185–186
- production code on, 184–185
- small, 185
- transferring drive to, 184, 185

 linear clutches, 83–84  
 linear motion, converting rotary motion to, 71–72  
 linear speed, defined, 3  
 linkages, 71–76
 

- Chebyshev linkage, 73
- Hoeken's linkage, 73
- and levers, 69–71
- pantograph, 73
- Peaucellier–Lipkin cell, 74
- rocking motion of, 71, 74
- Sarrus linkage, 74–75
- scissor linkage, 75–76
- Scott-Russell linkage, 75
- Watt's linkage, 76

 live axle. *See* floating axle suspension  
 load
 

- of levers, 67, 70
- rotating under large loads, 55

 load-bearing structures, 151–159
 

- rails, chassis, and body frames, 151–153
- trusses, 154–159
  - Brown truss, 155–156
  - choosing, 157–159
  - triangular Warren truss, 156–157
  - Warren truss, 156

 locking mechanisms, 82–83

long pins, 11, 12  
 longitudinal subtractor, 282–287  
 longnose trucks, 296–298  
 LPE (LEGO pneumatic engine), 124–134  
 L-shaped beams, 143  
 luff tackle, 63

**M**

M (Medium) motor, Power Functions, 28, 168  
 Maltese cross mechanisms. *See* Geneva mechanisms  
 MAN TGS truck, 298  
 manometer, 112  
 maximum steering angle, 6  
 mechanical advantage, 61–62
 

- levers, 67, 72
- pulley systems
  - differential pulley system, 64–65
  - power pulley system, 65–66
  - simple pulley system, 62–63

 mechanical power, defined, 3  
 mechanical solutions, custom, 77–101
 

- differential, 77–78
- differential locks, 78–82
- double-axle turntable transmission, 96–100
- eccentric mechanisms, 84–85
- flashing lights, 91–92
- Geneva mechanisms, 89–90
- linear clutches, 83–84
- Oldham couplings, 87–88
- ratchets, 82–83
- reverse lights, 90–91
- Schmidt couplings, 88
- Scotch yokes, 85–86
- stepper motors, 88–89
- turn signals, 92–95
- universal joint, 101

 mechanics, vs. pneumatics, 47  
 Medium (M) motor, Power Functions, 28, 168  
 microleaks, 103  
 Micromotor, 166–167  
 Micromotor pulley, 59, 65  
 mineral oil, 113  
 misaligned pieces, 27  
 MOCs (My Own Creations), 17  
 Model Team approach, 26

modeling process, 315–324  
 circular elements, 316–319  
 colors, 319–320  
 details, 320–323  
 odd angles, 321–322  
 size considerations, 315–316  
 wheels, 316–319

modified axles, 32, 33

module, 9

Monster Truck model, 17, 207

motorcycles, 299, 300

motorized compressors, 115–119

motorized valves, 119–120

motors, 163–170  
 2838, 164–165  
 43362, 165  
 47154, 166  
 71427, 165  
 complexity of, 316  
 controlling  
 manually, 171–172  
 remotely, 172–174  
 coupling with adders, 277–280  
 Micromotor, 166–167  
 NXT motor, 167  
 Power Functions E motor, 167  
 Power Functions L motor, 168  
 Power Functions Medium (M) motor, 168  
 Power Functions Servo motor, 169  
 Power Functions XL motor, 169  
 RC motor, 170  
 stepper, 88–89

mudguards, 317

My Own Creations (MOCs), 17

## N

N•cm (Newton centimeters), 3

new LEGO pieces, vs. old, 159–160

Newton centimeters (N•cm), 3

Newton's law of action and reaction, 138

nonlinear (regular) transmissions, 252

nonrigid connections, 21

number:number ratio, weight distribution, 7

NXT motor, 167

## O

obsolete gears, 56

odd angles, 321–322

old LEGO pieces vs. new, 159–160

Oldham couplings, 87–88

old-type gears, 48

one-way valve, 104

output axle, 44

overdrive, 46

## P

Pagani Zonda, 296, 307

Paint application, 310

pantograph, 73

parallel levers, 70, 71

pawls, 82–83

Peaucellier–Lipkin cell, 74

pendular axles  
 portal, 230–235  
 steered, 225  
 with worm gear, 236–240

pendular suspension, 208–209  
 stabilized, 211–214  
 stabilized with portal axle, 214–217  
 with turntables, 210–213

perpendicular gears, reinforcing, 142, 143

personnel carriers  
 BMR-2, 322  
 Hagglunds BV 206, 300  
 RG-35 4x4 MRAP vehicle, 26, 214

Peterbilt truck, 298, 313

photographs, using instead of  
 blueprints, 308

pin holes, 10

pins  
 axle, 11, 12, 83, 84  
 friction, 11  
 half, 11, 12  
 long, 11, 12  
 overview, 10–12  
 specialized, 11–12  
 three-quarter, 11, 14–15  
 with towball, 12  
 using to connect bricks and beams, 27

planar trusses, 154

planes, 302

planet gears, 278

plates  
 disadvantage of using, 20  
 height of, 9  
 reinforcing parts using, 141

plugs  
 adapter, 186  
 stackable, 171

pneumatic devices, 115–136. *See also*  
 pneumatic system  
 automated pressure switch, 123–124  
 autovalve, 120–122  
 builder showcase, 135  
 motorized compressors, 115–119  
 motorized valves, 119–120  
 pneumatic engines, 124–134  
 overview, 124–125  
 single-cylinder, 125–127  
 two-cylinder, 128–134  
 water pressure pump, 135–136

pneumatic system, 103–113. *See also*  
 pneumatic devices  
 avoiding backlash using, 47  
 vs. linear actuators, 185–186  
 microleaks in, 103  
 modifying, 112–113  
 non-LEGO airtanks, 112  
 non-LEGO hoses, 112  
 pneumatic suspensions, 113  
 removing springs to create motorized  
 compressors, 113  
 turning pneumatic system into  
 hydraulic, 113

New system, 104–105

Old system, 103–104

parts of, 105–112  
 6L cylinder, 107  
 airtank, 111  
 cylinder bracket, 110–111  
 distribution block, 106  
 hose connector with axle joint, 110  
 large cylinder, 107, 108  
 manometer, 112  
 pneumatic pump, 103, 104, 105–106  
 pneumatic tubes and hoses, 108–109  
 small cylinder, 108  
 T-piece, 109–110  
 valve with studs, 106–107  
 PTO (power take-off), 110

points. *See* fulcrums

points of reference, 309

portal axles (geared hubs), 213–217, 318

power, 3

Power Functions system, 171–188  
 extension wires, 186–187  
 IR receiver, 28  
 LED lights, 91–92, 187–188  
 linear actuators, 183–186

- motors, 163–164
  - controlling, 171–174
  - E motor, 167
  - L motor, 168
  - Medium (M) motor, 168
  - Servo motor, 169
  - XL motor, 169
- power supplies, 172–175
- receiver, 175–176
- remotes, 176–177
  - controlling, 172–174
  - modifying, 177–182
- switches, 28, 90, 92
- power pulley system, 65–66
- power supply, 173
- power take-off (PTO), 110
- powertrain, 6
- pressure generator, 103
- pressure switch, automated, 123–124
- production code, on linear actuators, 184–185
- propellers, 302, 303
- PTO (power take-off), 110
- pulleys, 59–61
  - vs. chains, 60
  - in Micromotor, 167
  - ratios between, 59–60
  - rubber bands used with, 60
  - slippage, 60
  - string and pulley systems, 61–66
    - differential pulley system, 63–65
    - power pulley system, 65–66
    - simple pulley system, 62–63
- pumps, pneumatic, 105–106
  - in motorized compressors, 115–116
  - in New system, 104
  - in Old system, 103
- pushrods, 84

## R

- rack gear, 193
- rack-and-pinion gearset, 191
- racks, driving with worm gear, 49
- radius, turning, 6–7, 199
- rails, 151–153
- ratchets, 82–83
- RC motor, 170
- reach stacker, 7
- rear-wheel drive (RWD), 7

- receivers, 172–176
- receiving mechanism, 6
- rechargeable battery, 175
- red pieces, strength of, 160
- regular (nonlinear) transmissions, 252
- regular LEGO bricks, 18
- reinforcement, 137–160. *See also* load-bearing structures
  - choosing strongest pieces, 159–160
  - defined, 19
  - of differential casings, 144–148
  - right way to reinforce, 140–144
  - where to reinforce, 138–140
  - why things fall apart, 137–140
  - of worm gear casings, 149–150
- remotes, 176–177
  - with central steering wheel, 181–183
  - modifying, 177–182
  - multiple, using simultaneously, 174
  - with sideways lever, 179
  - with steering wheel, 178
  - using many receivers with single remote, 173
- resistance, and surfaces, 4–5
- return rollers, 245
- return-to-center steering, 194–195
- reverse gear, in transmissions, 254
- reverse lights, 90–91
- RG-35 4×4 MRAP vehicle, 26, 26, 214
- ride height, 8
- rigid connections
  - vs. nonrigid connection, 21
  - between perpendicular beams, 22
  - using single axle, 21
- ripple, of motorized compressors, 115
- road wheels, 245, 249–250
- rocking compressor, 116–117, 118
- rocking motion
  - converting rotary motion to, 84–85
  - converting to linear motion, 71
  - of linkages, 71, 74
- rolling resistance, 4–5
- rotary motion
  - continuous, converting into intermittent, 89
  - converting to linear motion, 71–72
  - converting to rocking motion, 84–85
- rotational direction of gears, controlling, 47–48
- rotational speed, defined, 3

- rotors, 303–305
- RPM (rotations per minute), 3
- rubber bands
  - used for self-centering steering, 195
  - used with CVTs, 260
  - used with pulleys, 60
- rubber tracks, 241
- RWD (rear-wheel drive), 7

## S

- Sarrus linkage, 74–75
- scaling, 307–314
  - and blueprints, 307–309
  - and points of reference, 309
- Schmidt couplings, 88
- scissor linkage, 75–76
- Scotch yokes, 85–86
- Scott-Russell linkage, 75
- seams, weak, 138
- sequential (linear) transmissions, 252
- Servo motor, Power Functions, 169
- sets, Technic, 24–26
- shock absorbers, 209, 211
  - alternative to, 248–249
  - flexible axles as, 34
  - for road wheels in a track, 247
  - Tatra-type suspension stabilized with, 217–220
  - trailing arms suspension with, 247
  - used with chains, 58
- side gears (spider gears), 278
- sidecars, 299
- sideways lever, remotes with, 179–180
- Sikorsky MH-53 Pave Low helicopter, 303, 313
- single-bevel gears, 50, 51
- single-cylinder pneumatic engines, 125–127
- size considerations, 315–316
- size of parts, and efficiency, 5
- sliders, 130
- sliding worm gear, 120
- slippage
  - of 24-tooth gear with clutch, 52
  - and differentials, 78, 80
  - in pulley system, 60
- small cylinder, 108
- smooth half bush, with cutout, 37
- snow groomer, 25
- soft axles. *See* flexible axles

solid tracks. *See* hard plastic tracks

space trusses, 154

specialized pins, 11–12

speed

- and mechanical advantage, 61–62
- traction, 3
- transforming using gears, 43

speed control remote, 176–177, 181–182

spider gears (side gears), 278

spindles, 191

splitting hoses, 110

sprocket wheels, 243, 244–245, 250

sprung suspension systems, 205

stabilized suspension

- pendular, 211–217
- Tatra-type, 217–220

stackable plugs, 171

standard axles, 32

steering geometry, 195–198, 317

steering lock, 6

steering systems, wheeled, 178, 181, 191–202

- convergence of axles, 199–202
- return-to-center steering, 194–195
- steering geometry, 195–198, 317

stepper motors, 88–89

stopping vehicles, 177

string and pulley systems, 61–66

- differential pulley system, 63–65
- power pulley system, 65–66
- simple pulley system, 62–63

stringers. *See* rails

structural reinforcement. *See* reinforcement

stud measurement, defined, 9

studfull vs. studless building, 17–30

- aligning studless pieces with studfull, 13
- combining styles, 23–30
- matching widths, 28–30
- methods for connecting bricks and beams, 27–28
- Technic sets, 24–26

overview, 17–18

studfull, 18–20

studless, 19, 20–23, 29, 144

studless transverse subcontractor, 291–292

studs

- half studs, 14–15
- valve with, 106–107

subtractors, 280–292

- longitudinal subtractor, 282–287
- reasons for using, 281–282
- transverse subtractor, 288–292

surfaces

- and friction, 4
- and resistance, 4–5

suspension systems, 246–249. *See also* wheeled suspension systems

- bogies, 246–247
- pneumatic, 113
- trailing arm suspensions, 247–249

SUVs, 7, 296

- 8466 4×4 Off-Roader, 24
- 8850 Jeep, 24

switches

- automated pressure, 123–124
- Power Functions, 28, 90, 92, 172

synchronized transmissions, 251–252, 261

**T**

T-72M tank, 301, 320, 321

tanks, 299–301

- barrels of, 320, 321
- British Churchill, 245
- guns of, 323
- Leopard 2A4, 301, 323
- road wheels on, 245
- Sherman, 246
- Soviet, 245, 250
- suspension system, 244
- T-72M, 301, 320, 321
- turning radius of, 6
- using wedge belt wheels with tires, 250

Tatra-type suspension, 207–208, 217–220

Tchebycheff's linkage, 73

Technic sets, 24–26

threaded axles, 33

threefold purchase, 64

three-quarter pins, 11, 14–15

tie rods, 193–194, 196–197

timers, in battery boxes, 174, 175

tires. *See also* wheels

- size of, 317
- traction, 4

toothed half bushes, 35–36

top mast, 159

torque. *See also* axles; chains; gears; pulleys and coupling motors, 277–280

- and extension driving ring, 253
- and knob wheels, 55
- and mechanical advantage, 61–62
- overview, 3
- summing with adders, 277–279

torque ratio, 45

torsion bars, 248–249

Tow Truck 2 model, 153, 316

tower cranes, 154, 158–159

T-pieces, 109–110

tracked vehicles. *See also* chains; tanks

- favoring form or function, 299–301
- hard plastic tracks, 242–244
- with road wheels, 249–250
- rubber tracks, 241
- speed control remote for, 181–182
- tracked wheel systems, 244–246
- using subtractors with, 280–281
- and weight distribution, 7

traction, 4

trailing arm (floating axle) suspension, 209, 222–224, 248–249

transmission changeover catch, 80, 252–253

transmission driving rings, 51, 259

transmissions, 251–276. *See also* gears

- 2-speed

  - linear heavy-duty, 254, 262–264
  - orbital, 255
  - ratchet, 256, 267
  - RC motor, 255, 264–265
  - synchronized, 254

- 3-speed, 256, 268–269
- 4-speed, 257–258, 270–271
- 5-speed, 258
- 10-speed, 259, 271–275

changeover catch, 252–253

combining, 254

continuously variable (CVTs), 260, 276

distribution transmissions, 260–276

double-axle turntable, 96–100

driving rings, 252–254

- regular (nonlinear), 252
- sequential (linear), 252
- synchronized, 251–252, 261

transverse subtractor, 288–292

tread hubs, 241

triangular Warren truss, 156–157



trucks, 296–299  
 8436 Truck set, 30  
 half-track, 301  
 Kenworth Road Train model, 18  
 MAN TGS, 298  
 Monster Truck model, 17  
 Peterbilt, 298, 313  
 Tow Truck 2 model, 153, 316

trusses, 154–159  
 Brown truss, 155–156  
 choosing, 157–159  
 triangular Warren truss, 156–157  
 Warren truss, 156

tubes, pneumatic, 108–109

turn signals, 92–95

turning radius, 6–7, 199

turntable transmission, 96–100

turntables, 54–55

two-cylinder pneumatic engines, 128–134

## U

universal joints, 38–39, 101  
 alternative to, 87  
 and high torque, 38  
 length of, 38  
 making sturdy, 101

unsprung suspension systems, 205

US trucks, 296–298

## V

valves  
 motorized, 119–120  
 in New LEGO pneumatic system, 104  
 with no studs, 107  
 in Old LEGO pneumatic system, 103, 104  
 with studs, 106–107

voltage, 3

## W

wall-to-wall turning radius, 6

Warren truss, 156

water pressure pump, 135–136

Watt's linkage, 72, 76

wear of LEGO pieces, 159–160

wedge belt wheel, 59  
 at center of hub, 305  
 in differential pulley system, 63  
 in pneumatic engines, 124  
 thickness of, 60  
 use with tracked vehicles, 249–250

weight distribution, 7

weight of parts, and efficiency, 5

wheelbarrow, 69

wheeled steering systems, 178, 181, 191–202  
 Ackermann steering geometry, 195–198  
 convergence of axles, 199–202  
 return-to-center steering, 194–195

wheeled suspension systems, 203–240  
 dependent suspension, defined, 204  
 driven and suspended axles, 209–224  
 pendular suspension with turntables, 210–213  
 portal axles (geared hubs), 213–217  
 driven axles, 203  
 floating axle (trailing arm) suspension, 209, 222–224, 248–249  
 ground clearance, 205  
 independent suspension, 220–221  
 defined, 204  
 double-wishbone, 206–207  
 pendular suspension, 208–209  
 stabilized pendular suspension, 211–214  
 stabilized pendular suspension with portal axle, 214–217  
 sprung/unsprung, 205  
 Tatra-type suspension, 207–208, 217–220

wheels  
 knob wheels, 55, 203  
 and modeling process, 316–319  
 road wheels, 245, 249–250  
 sprocket wheels, 243, 244–245, 250  
 wedge belt wheels, 59  
 at center of hub, 305  
 in differential pulley system, 63  
 in pneumatic engines, 124  
 thickness of, 60  
 use with tracked vehicles, 249–250

Windows Paint application, 310

wings, 302

worm gears, 48–49  
 backlash with, 47  
 boom-extending mechanism with, 49  
 as driver gear, 48  
 driving racks with, 49  
 gearing down with, 48, 49  
 to lock mechanisms, 82  
 pendular portal axle with, 236–240  
 reinforcing casings of, 149–150  
 sliding, 120  
 in valve-switching mechanism, 120  
 wear of, 160

## Y

yellow pieces, strength of, 160

yokes  
 defined, 38  
 Scotch, 85–86

## Z

zero, turning radius of, 6