



40 Inventive Principles With Examples

Principle 1 Segmentation

- A. *Divide an object into independent parts*
- Different focal length lenses for a camera
 - Gator-grip socket spanner
 - Multi-pin connectors
 - Multiple pistons in an internal combustion engine
 - Multi-engined aircraft
 - Stratification of different constituents inside a chemical process vessel
- B. *Make an object sectional - easy to assemble or disassemble*
- Rapid-release fasteners for bicycle saddle/wheel/etc
 - Quick disconnect joints in plumbing and hydraulic systems
 - Single fastener V-band clamps on flange joints
 - Loose-leaf paper in a ring binder
- C. *Increase the degree of fragmentation or segmentation*
- Multiple control surfaces on aerodynamic structures
 - 16 and 24 valve versus 8 valve internal combustion engines
 - Multi-zone combustion system
 - Build up a component from layers (e.g. stereo-lithography, welds, etc)

Principle 2 Taking out

- A. *Extract the disturbing part or property from an object*
- Non-smoking areas in restaurants or in railway carriages
 - Children-only areas in public places and home
 - Sunday school
 - Public bars and lounge bars in pubs
 - Women or men only bars / waiting rooms
 - Air Conditioning in the room where you want it with the noise of the system outside the room
- (The contradiction here is noise vs coolness- the cooler it gets the noisier it gets- this solves the contradiction by putting the noise elsewhere)*
- B. *Extract the only necessary part (or property) of an object*
- Scarecrow
 - Sound of a barking dog (with no dog) as a burglar alarm
 - Economy class on planes (travel but no frills)

(This involves understanding all the functionality and selecting only what you want- e.g. windows provide ventilation and light - with air conditioning you may not need windows which open)



Principle 3 Local quality

A. Change of an object's structure from uniform to non-uniform

- Reduce drag on aerodynamic surfaces by adding riblets or 'shark-skin' protrusions
- Moulded hand grips on tools
- Drink cans shaped to facilitate stable stacking
- Material surface treatments / coatings - plating,
- Erosion / corrosion protection, case hardening, non-stick, etc

B. Change an action or an external environment (or external influence) from uniform to non-uniform

- Introduce turbulent flow around an object to alter heat transfer properties
- Strobe lighting
- Take account of extremes of weather conditions when designing outdoor systems
- Use a gradient instead of constant temperature, density, or pressure

C. Make each part of an object function in conditions most suitable for its operation

- Freezer compartment in refrigerator
- Different zones in the combustion system of an engine
- Night-time adjustment on a rear-view mirror
- Lunch box with special compartments for hot and cold solid foods and for liquids

D. Make each part of an object fulfil a different and/or complementary useful function

- Swiss-Army knife
- Combined can and bottle opener
- Sharp and blunt end of a drawing pin
- Rubber on the end of a pencil
- Hammer with nail puller



Principle 4 Asymmetry

A. Change the shape or properties of an object from symmetrical to asymmetrical

- Asymmetrical funnel allows higher flow-rate than normal funnel
- Put a flat spot on a cylindrical shaft to attach a locking feature
- Oval and complex shaped O-rings
- Coated glass or paper
- Electric Plug
- Introduction of angled or scarfed geometry features on component edges
- Cutaway on a guitar improves access to high notes
- Spout of a jug
- Cam
- Ratchet
- Aerofoil – asymmetry generates lift
- Eccentric drive
- Keys

B. Change the shape of an object to suit external asymmetries (e.g. ergonomic features)

- Human-shaped seating, etc
- Design for left and right handed users
- Finger and thumb grip features on objects
- Spectacles
- Car steering system compensates for camber in road
- Wing design compensated for asymmetric flow produced by propeller
- Turbomachinery design for boundary layer flows ('end-bend')

C. If an object is asymmetrical, increase its degree of asymmetry

- Use of variable control surfaces to alter lift properties of an aircraft wing
- Special connectors with complex shape/pin configurations to ensure correct assembly
- Introduction of several different measurement scales on a ruler



Principle 5 Merging

A. Bring closer together (or merge) identical or similar objects or operations in space

- Automatic rifle / machine gun
- Multi-colour ink cartridges
- Multi-blade razors
- Bi-focal lens spectacles
- Double / triple glazing
- Strips of staples
- Catamaran / trimaran

B. Make objects or operations contiguous or parallel; bring them together in time

- Combine harvester
- Manufacture cells
- Grass collector on a lawn-mower
- Mixer taps
- Pipe-lined computer processors perform different stages in a calculation simultaneously
- Vector processors perform the same process on several sets of data in a single pass
- Fourier analysis – integration of many sine curves

Principle 6 Universality

A. Make an object perform multiple functions; eliminate the need for other parts

- Child's car safety seat converts to a pushchair
- Home entertainment centre
- Swiss Army knife
- Grill in a microwave oven
- CD used as a storage medium for multiple data types
- Cleaning strip at beginning of a cassette tape cleans tape heads
- Cordless drill also acts as screwdriver, sander, polisher, etc



Principle 7 Nested Doll

A. Place one object inside another

- Retractable aircraft under-carriage
- Voids in 3D structures
- Injected cavity-wall insulation
- Paint-brush attached to inside of lid of nail-varnish, etc
- Lining inside a coat

B. Place multiple objects inside others

- Nested tables
- Telescope
- Measuring cups or spoons
- Stacking chairs
- Multi-layer erosion/corrosion coatings

C. Make one part pass (dynamically) through a cavity in the other

- Telescopic car aerial
- Retractable power-lead in vacuum cleaner
- Seat belt retraction mechanism
- Tape measure

Principle 8 Anti-Weight

A. To compensate for the weight of an object, merge it with other objects that provide lift

- Kayak with foam floats built into hull cannot sink
- Aerostatic aeroplane contains lighter-than-air pockets
- Hot air or helium balloon
- Swim-bladder inside a fish
- Flymo cutting blade produces lift

B. To compensate for the weight of an object, make it interact with the environment (use aerodynamic, hydrodynamic, buoyancy and other forces)

- Vortex generators improve lift of aircraft wings
- Wing-in-ground effect aircraft
- Hydrofoils lift ship out of the water to reduce drag
- Make use of centrifugal forces in rotating systems (e.g. Watt governor)
- Maglev train uses magnetic repulsion to reduce friction



Principle 9 Prior Counteraction

A. When it is necessary to perform an action with both harmful and useful effects, this should be replaced with counteractions to control harmful effects

- Make clay pigeons out of ice or dung - they just melt away
- Masking objects before harmful exposure: use a lead apron for X-rays, use masking tape when painting difficult edges etc.
- Predict effects of signal distortion - compensate before transmitting
- Buffer a solution to prevent harm from extremes of pH

B. Create beforehand stresses in an object that will oppose known undesirable working stresses later on

- Pre-stress rebar before pouring concrete
- Pre-stressed bolts
- Decompression chamber to prevent divers getting the bends

Principle 10 Prior Action

A. Perform the required change of an object in advance

- Pre-pasted wall paper
- Sterilize all instruments needed for a surgical procedure
- Self-adhesive stamps
- Holes cut before sheet-metal part formed
- Pre-impregnated carbon fibre reduces lay-up time and improves "wetting"

B. Pre-arrange objects such that they can come into action from the most convenient place and without losing time for their delivery

- Manufacture flow-lines
- Pre-deposited blade in a surgery cast facilitates removal
- Car jack, wheel brace, and spare tyre stored together
- Collect all the tools and materials for the job before starting

Principle 11 Cushion in Advance

A. Prepare emergency means beforehand to compensate for the relatively low reliability of an object ('belt and braces')

- Multi-channel control system
- Air-bag in a car / Spare wheel / Battery back-up / Back-up parachute
- Pressure relief valve
- Emergency lighting circuit
- Automatic save operations performed by computer programs
- Crash barriers on motorways
- 'Touch-down' bearing in magnetic bearing system



Principle 12 Equipotentiality

A. If an object has to be raised or lowered, redesign the object's environment so the need to raise or lower is eliminated or performed by the environment

- Canal locks
- Spring loaded parts delivery system in a factory
- Mechanic's pit in a garage means car does not have to be lifted
- Place a heavy object on ice, and let ice melt in order to lower it
- Angle-poise lamp; changes in gravitational potential stored in springs
- Descending cable cars balance the weight of ascending cars

Principle 13 The Other Way Round

A. Invert the action used to solve the problem

- To loosen stuck parts, cool the inner part instead of heating the outer part
- Vacuum casting
- Rotary engines
- Test pressure vessel by varying pressure outside rather than inside
- Test seal on a liquid container by filling with pressurised air and immersing in liquid; trails of bubbles are easier to trace than slow liquid leaks

B. Make movable parts (or the external environment) fixed, and fixed parts movable

- Hamster wheel
- Escalator
- Rotate the part instead of the tool
- Wind tunnels
- Moving sidewalk with standing people
- Drive through restaurant or bank

C. Turn the object (or process) 'upside down'.

- Clean bottles by inverting and injecting water from below
- Turn an assembly upside down to insert fasteners



Principle 14 Spheroidality – Curvature

A. Move from flat surfaces to spherical ones and from parts shaped as a cube (parallelepiped) to ball-shaped structures

- Use arches and domes for strength in architecture
- Introduce fillet radii between surfaces at different angles
- Introduce stress relieving holes at the ends of slots
- Change curvature on lens to alter light deflection properties

B. Use rollers, balls, spirals

- Spiral gear (Nautilus) produces continuous resistance for weight lifting
- Ball point and roller point pens for smooth ink distribution
- Use spherical casters instead of cylindrical wheels to move furniture
- Archimedes screw

C. Go from linear to rotary motion (or vice versa)

- Rotary actuators in hydraulic system
- Switch from reciprocating to rotary pump
- Push/pull versus rotary switches (e.g. lighting dimmer switch)
- Linear motors
- Linear versus rotating tracking arm on a record turntable ensures constant angle of stylus relative to groove
- Screw-thread versus nail

D. Use centrifugal forces

- Centrifugal casting for even wall thickness structures
- Spin components after painting to remove excess paint
- Remove water from clothes with a spin dryer rather than a mangle
- Separate chemicals with different density properties using a centrifuge
- Watt governor
- Vortex/cyclone separates different density objects



Principle 15 Dynamics

A. Change the object (or outside environment) for optimal performance at every stage of operation

- Gel fillings inside seat allow it to adapt to user
- Adjustable steering wheel (or seat, or back support, or mirror position...)
- Shape memory alloys/polymers
- Racing car suspension adjustable for different tracks and driving techniques
- Car handbrake adjustable to account for brake pad wear
- Telescopic curtain rail - "one size fits all"

B. Divide an object into parts capable of movement relative to each other

- Bifurcated bicycle saddle
- Articulated lorry
- Folding chair/mobile phone/laptop/etc
- Collapsible structures
- Brush seals

C. Change from immobile to mobile

- Bendy drinking straw
- Flexible joint
- Collapsible hose is flexible in use, and has additional flexibility of cross-section to make it easier to store

D. Increase the degree of free motion

- Use of different stiffness fibres in toothbrush – easily deflected at the edges to prevent gum damage, hard in the middle
- Flexible drive allows motion to be translated around bends
- Loose sand inside truck tyre gives it self-balancing properties at speed
- Add joints to robot arm to increase motion possibilities

Principle 16 Partial or Excessive Action

A. If you can't achieve 100 percent of a desired effect - then go for more or less

- Over spray when painting, then remove excess
- Fill, then "top off" when pouring a pint of Guinness
- Shrink wrapping process uses plastic deformation of wrapping to accommodate variations in vacuum pressure
- 'Roughing' and 'Finish' machining operations
- Over-fill holes with plaster and then rub back to smooth



Principle 17 Another Dimension

A. Move into an additional dimension - from one to two - from two to three

- Coiled telephone wire
- Curved bristles on a brush
- Pizza-box with ribbed (as opposed to flat) base
- Spiral staircase uses less floor area
- Introduction of down and up slopes between stations on railway reduces overall power requirements

B. Go from single storey or layer to multi-storey or multi-layered

- Player with many CDs
- Stacked or multi-layered circuit boards
- Multi-storey office blocks or car-parks

C. Incline an object, lay it on its side

- Cars on road transporter inclined to save space

D. Use the other side

- Press a groove onto both sides of a record
- Mount electronic components on both sides of a circuit board
- Print text around the rim of a coin
- Paper clip - works by pressing both sides of paper together



Principle 18 Mechanical Vibration

A. *Cause an object to oscillate or vibrate*

- Electric carving knife with vibrating blades
- Shake/stir paint to mix before applying
- Hammer drill
- Vibration exciter removes voids from poured concrete
- Vibrate during sieving operations to improve throughput
- Musical instrument

B. *Increase its frequency (even up to the ultrasonic)*

- Dog-whistle (transmit sound outside human range)
- Ultrasonic cleaning
- Non-destructive crack detection using ultrasound

C. *Use an object's resonant frequency*

- Destroy gallstones or kidney stones using ultrasonic resonance
- Bottle cleaning by pulsing water jet at resonant frequency of bottles
- Tuning fork
- Increase action of a catalyst by vibrating it at its resonant frequency

D. *Use piezoelectric vibrators instead of mechanical ones*

- Quartz crystal oscillations drive high accuracy clocks
- Piezoelectric vibrators improve fluid atomisation from a spray nozzle
- Optical phase modulator

E. *Use combined ultrasonic and electromagnetic field oscillations*

- Mixing alloys in an induction furnace
- Sono-chemistry
- Ultrasonic drying of films – combine ultrasonic with heat source



Principle 19 Periodic Action

- A. *Instead of continuous action, use periodic or pulsating actions*
- Hitting something repeatedly with a hammer
 - Pile drivers and hammer drills exert far more force for a given weight
 - Replace a continuous siren with a pulsed sound
 - Pulsed bicycle lights make cyclist more noticeable to drivers
 - Pulsed vacuum cleaner suction improves collection performance
 - Pulsed water jet cutting
 - ABS car braking systems
- B. *If an action is already periodic, change the periodic magnitude or frequency*
- Improve a pulsed siren with changing amplitude and frequency
 - Dots and dashes in Morse Code transmissions
 - Use AM, FM, PWM to transmit information
- C. *Use pauses between actions to perform a different action*
- Clean barrier filters by back-flushing them when not in use
 - Inkjet printer cleans heads between passes
 - Brush between suction pulses in vacuum cleaner
 - Multiple conversations on the same telephone transmission line
 - Use of energy storage means – e.g. batteries, fly-wheels, etc

Principle 20 Continuity of Useful Action

- A. *Carry on work without a break. All parts of an object operating constantly at full capacity*
- Flywheel stores energy when a vehicle stops, so the motor can keep running at optimum power
 - Constant output gas turbine in hybrid car, or APU in aircraft, runs at highest efficiency all the time it is switched on
 - Constant speed / variable pitch propeller
 - Self-tuning engine – constantly tunes itself to ensure maximum efficiency
 - Heart pacemaker
 - Improve composting process by continuously turning material
 - Continuous glass or steel production
- B. *Eliminate all idle or intermittent motion*
- Self-cleaning / self-emptying filter eliminates down-time
 - Print during the return of a printer carriage - dot matrix printer, daisy wheel printers, inkjet printers
 - Digital storage media allow 'instant' information access
 - Kayaks use double-ended paddle to utilise recovery stroke
 - Computer operating systems utilise idle periods to perform necessary housekeeping tasks



Principle 21 Rushing Through

A. *Conduct a process, or certain stages of it (e.g. destructible, harmful or hazardous operations) at high speed*

- Cut plastic faster than heat can propagate in the material, to avoid deforming the shape
- Shatter toffee with a hammer blow
- Drop forge
- Flash photography
- Super-critical shaft – run through resonant modes quickly
- Bikini waxing (ouch!)

Principle 22 Blessing in Disguise

A. *Use harmful factors (particularly, harmful effects of the environment or surroundings) to achieve a positive effect*

- Use waste heat to generate electric power
- Recycle scrap material as raw materials for another – e.g. chipboard
- Vaccination
- Lower body temperature to slow metabolism during operations
- Composting
- Use centrifugal energy in rotating shaft to do something useful – e.g. seal, or modulate cooling air
- Use pressure differences to help rather than hinder seal performance

B. *Eliminate the primary harmful action by adding it to another harmful action to resolve the problem*

- Add a buffering material to a corrosive solution (e.g. an alkali to an acid, or vice versa)
- Use a helium-oxygen mix for diving, to eliminate both nitrogen narcosis and oxygen poisoning from air and other nitrox mixes
- Use gamma rays to detect positron emissions from explosives

C. *Amplify a harmful factor to such a degree that it is no longer harmful*

- Use a backfire to eliminate the fuel from a forest fire
- Use explosives to blow out an oil-well fire
- Laser-knife cauterises skin/blood vessels as it cuts



Principle 23 Feedback

A. Introduce feedback to improve a process or action

- Automatic volume control in audio circuits
- Signal from gyrocompass is used to control simple aircraft autopilots
- Engine management system based on exhaust gas levels is more efficient than carburettor
- Thermostat controls temperature accurately
- Statistical Process Control - measurements are used to decide when to modify a process
- Feedback turns inaccurate op-amp into useable accurate amplifier

B. If feedback is already used, change its magnitude or influence in accordance with operating conditions

- Change sensitivity of an autopilot when within 5 miles of an airport
- Change sensitivity of a thermostat when cooling vs. heating, since it uses energy less efficiently when cooling
- Use proportional, integral and/or differential control algorithm combinations

Principle 24 Intermediary

A. Use an intermediary carrier article or intermediary process

- Play a guitar with a plectrum
- Use a chisel to control rock breaking/sculpting process
- Dwell period during a manufacture process operation

B. Merge one object temporarily with another (which can be easily removed)

- Gloves to get hot dishes out of an oven
- Joining papers with a paper clip
- Introduction of catalysts into chemical reaction
- Abrasive particles enhance water jet cutting
- Bouquet garni in cooking



Principle 25 Self-Service

A. An object must service itself by performing auxiliary helpful functions

- A soda fountain pump that runs on the pressure of the carbon dioxide used to carbonate the drinks. If it won't fizz it's empty!
- Halogen lamps regenerate the filament - evaporated material is re-deposited
- Self-aligning / self-adjusting seal
- Self-cleaning oven / glass / material
- Abradable materials used in gas turbines such that initial running-in 'cuts' optimum seals into lining

B. Use waste resources, energy, or substances

- Use heat from a process to generate electricity: co-generation
- Use animal waste as fertilizer
- Use food and lawn waste to create compost
- Use pressure difference to reinforce seal action

Principle 26 Copying

A. Replace unavailable, expensive or fragile object with available or inexpensive copies

- Imitation jewellery
- Astroturf
- Crash test dummy

B. Replace an object, or process with optical copies

- Do surveying from space photographs instead of on the ground
- Measure an object by scaling measurements from a photograph
- Virtual reality / Virtual mock-ups / electronic pre-assembly modelling

C. If visible optical copies are used, move to infrared or ultraviolet copies

- Make images in infrared to detect heat sources, such as diseases in crops, or intruders in a security system
- Use UV as a non-destructive crack detection method
- UV light used to attract flying insects into trap

Principle 27 Cheap Short-Living Objects

A. Replace an expensive object with a multiple of inexpensive objects, compromising certain qualities, such as service life

- Disposable nappies / paper-cups / plates / cameras / torches etc
- Matches versus lighters
- Throw-away cigarette lighters
- Sacrificial coatings / components



Principle 28 Replace Mechanical System

- A. *Replace a mechanical system with a sensory one*
- Replace a physical barrier with an acoustic one (audible to animals)
 - Add a bad smell to natural gas to alert users to leaks
 - Finger-print/retina/etc scan instead of a key
 - Voice activated telephone dialling
- B. *Use electric, magnetic and electromagnetic fields to interact with the object*
- To mix 2 powders, electrostatically charge one positive and the other negative
 - Electrostatic precipitators separate particles from airflow
 - Improve efficiency of paint-spraying by oppositely charging paint droplets and object to be painted
 - Magnetic bearings
 - Field activated switches
- C. *Replace stationary fields with moving; unstructured fields with structured*
- Early communications used omni-directional broadcasting. We now use antennas with very detailed structure of the pattern of radiation
 - Magnetic Resonance Imaging (MRI) scanner
- D. *Use fields in conjunction with field-activated (e.g. ferromagnetic) particles*
- Heat a substance containing ferromagnetic material by using varying magnetic field. When the temperature exceeds the Curie point, the material becomes paramagnetic, and no longer absorbs heat
 - Magneto-rheological effect – uses ferromagnetic particles and variable magnetic field to alter the viscosity of a fluid
 - Ferro-magnetic catalysts
 - Ferro-fluids – e.g. Magnatec oil – stay attached to surfaces requiring lubrication

Principle 29 Pneumatics and Hydraulics

- A. *Use gas and liquid parts of an object instead of solid parts (e.g. inflatable, filled with liquids, air cushion, hydrostatic, hydro-reactive)*
- Transition from mechanical to hydraulic or pneumatic drive
 - Inflatable furniture / mattress etc
 - Gel filled saddle adapts to user
 - Hollow section O-rings
 - Hovercraft
 - Gas bearings
 - Acoustic panels incorporating Helmholtz resonators



Principle 30 Flexible Membranes/Thin Films

- A. *Use flexible shells and thin films instead of three-dimensional structures*
- Use inflatable (thin film) structures
 - Taut-liner trucks
 - Tarpaulin car cover instead of garage
 - Store energy in stretchable bags – accumulators in a hydraulic system
- B. *Isolate the object from its external environment using flexible membranes*
- Bubble-wrap
 - Bandages/plasters
 - Tea bag
- Shrink wrapping

Principle 31 Porous Materials

- A. *Make an object porous or add porous elements (inserts, coatings, etc.)*
- Drill holes in a structure to reduce the weight
 - Cavity wall insulation
 - Transpiration film cooled structures
 - Foam metals
 - Use sponge-like structures as fluid absorption media
- B. *If an object is already porous, use the pores to introduce a useful substance or function*
- Use a porous metal mesh to wick excess solder away from a joint
 - Store hydrogen in the pores of a palladium sponge. (Fuel "tank" for the hydrogen car - much safer than storing hydrogen gas)
 - Desiccant in polystyrene packing materials
 - Medicated swabs/dressings



Principle 32 Colour Change

A. *Change the colour of an object or its external environment*

- Use safe lights in a photographic darkroom
- Use colour-changing thermal paint to measure temperature
- Plastic spoon which changes colour when hot - for baby food
- Temperature-sensitive dyes used on food product labels to indicate when desired serving temperature has been achieved
- Electrochromic glass
- Light-sensitive glasses
- Camouflage
- Dazzle camouflage used on World War 1 ships
- Employ interference fringes on surface structures to change colour (as in butterfly wings, etc)

B. *Change the transparency of an object or its external environment*

- Use photolithography to change transparent material to a solid mask for semiconductor processing
- Light-sensitive glass

C. *In order to improve observability of things that are difficult to see, use coloured additives or luminescent elements*

- Fluorescent additives used during UV spectroscopy
- UV marker pens used to help identify stolen goods
- Use opposing colours to increase visibility – e.g. butchers use green decoration to make the red in meat look redder

D. *Change the emissivity properties of an object subject to radiant heating*

- Use of black and white coloured panels to assist thermal management on space vehicles
- Use of parabolic reflectors in solar panels to increase energy capture
- Paint object with high emissivity paint in order to be able to measure its temperature with a calibrated thermal imager

Principle 33 Homogeneity

A. *Objects interacting with the main object should be of same material (or material with identical properties)*

- Container made of the same material as its contents, to reduce chemical reactions
- Friction welding requires no intermediary material between the two surfaces to be joined
- Temporary plant pots made out of compostable material
- Human blood transfusions/transplants, use of bio-compatible materials
- Make ice-cubes out of the same fluid as the drink they are intended to cool
- Join wooden components using (wood) dowel joints



Principle 34 Discarding and Recovering

A. After completing their function (or becoming useless) reject objects, make them go away, (discard them by dissolving, evaporating, etc) or modify during the process

- Dissolving capsule for medication.
- Bio-degradable containers, bags etc.
- Casting processes – lost-wax, sand, etc.
- During firing of a rocket, foam protection is used on some elements; this evaporates in space when shock-absorbance is no longer required

B. Restore consumable / used up parts of an object during operation

- Self-sharpening blades – knives / lawn-mowers etc
- Strimmer dispenses more wire automatically after a breakage
- Self-tuning automobile engines
- Propelling pencil
- Automatic rifle

Principle 35 Parameter Change

A. Change the physical state (e.g. to a gas, liquid, or solid)

- Transport oxygen or nitrogen or petroleum gas as a liquid, instead of a gas, to reduce volume

B. Change the concentration or density

- Liquid soap
- Abradable linings used for gas-turbine engine seals

C. Change the degree of flexibility

- Vulcanize rubber to change its flexibility and durability
- Compliant brush seals rather than labyrinth or other fixed geometry seals

D. Change the temperature or volume

- Raise the temperature above the Curie point to change a ferromagnetic substance to a paramagnetic substance
- Cooking / baking etc.

E. Change the pressure

- Pressure cooker cooks more quickly and without losing flavours
- Electron beam welding in a vacuum
- Vacuum packing of perishable goods

F. Change other parameters

- Shape memory alloys/polymers
- Use Curie point to alter magnetic properties
- Thixotropic paints / gels etc.
- Use high conductivity materials – e.g. carbon fibre



Principle 36 Phase Transition

A. Use phenomena of phase transitions (e.g. volume changes, loss or absorption of heat, etc.)

- Latent heat effects in melting / boiling
- Soak rocks in water, then freezing causes water to expand – thus opening fissures in rock, making it easier to break
- Heat pumps use the heat of vaporization and heat of condensation of a closed thermodynamic cycle to do useful work
- Volume expansion during water-to-steam transition
- Superconductivity

Principle 37 Thermal Expansion

A. Use thermal expansion, or contraction, of materials

- Fit a tight joint together by cooling the inner part to contract, heating the outer part to expand, putting the joint together, and returning to equilibrium
- Metal tie-bars used to straighten buckling walls on old buildings
- Thermal switch/cut-out
- Shape memory alloys/polymers
- Shrink-wrapping

B. Use multiple materials with different coefficients of thermal expansion

- Bi-metallic strips used for thermostats, etc
- Two-way shape memory alloys
- Passive blade tip clearance control in gas turbine engines
- Combine materials with positive and negative thermal expansion coefficients to obtain alloys with zero (or specifically tailored) expansion properties – e.g. cerro-tru alloy used in the mounting and location of fragile turbine blade components during manufacture operations



Principle 38 Accelerated Oxidation

A. Replace common air with oxygen-enriched air

- Scuba diving with Nitrox or other non-air mixtures for extended endurance
- Place asthmatic patients in oxygen tent
- Nitrous oxide injection to provide power boost in high performance engines

B. Replace enriched air with pure oxygen

- Cut at a higher temperature using an oxy-acetylene torch
- Treat wounds in a high pressure oxygen environment to kill anaerobic bacteria and aid healing
- Control oxidation reactions more effectively by reacting in pure oxygen

C. Expose air or oxygen to ionising radiation

- Positive ions formed by ionising air can be deflected by magnetic field in order to (e.g.) reduce air resistance over an aerodynamic surface
- Irradiation of food to extend shelf life
- Use ionised air to destroy bacteria and sterilise food

D. Use ionised oxygen

- Speed up chemical reactions by ionising the gas before use
- Separate oxygen from a mixed gas by ionising the oxygen

E. Replace ozonised (or ionised) oxygen with ozone

- Oxidisation of metals in bleaching solutions to reduce cost relative to hydrogen peroxide
- Use ozone to destroy micro-organisms and toxins in corn
- Ozone dissolved in water removes organic contaminants from ship hulls

Principle 39 Inert Atmosphere

A. Replace a normal environment with an inert one

- Prevent degradation of a hot metal filament by using an argon atmosphere
- MIG/TIG welding
- Electron beam welding conducted in a vacuum
- Vacuum packaging
- Foam to separate a fire from oxygen in air

B. Add neutral parts, or inert additives to an object

- Naval aviation fuel contains additives to alter flash point
- Add fire retardant elements to titanium to reduce possibility of titanium fire
- Add foam to absorb sound vibrations – e.g. hi-fi speakers



Principle 40 Composite Materials

A. Change from uniform to composite (multiple) materials

- Aircraft structures where low weight and high strength are required
- Composites in golf club shaft
- Concrete aggregate
- Glass-reinforced plastic
- Fibre-reinforced ceramics
- Hard / soft / hard multi-layer coatings to improve erosion properties