

40 Principles – Chemical Illustrations

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Introduction

The origins of TRIZ are to be found in the analysis of engineering and utility patents of the former USSR. As such the 40 Principles of TRIZ were constructed to tackle engineering problems. Much work has been done attempting to extend the use of the principles into non-engineering situations, such as the 'soft' issues in business, personal or health. However, there has been less work published which aims TRIZ directly at chemistry and its applications. This paper is designed to initiate the discussion on how the 40 principles of TRIZ may be applied directly to chemical problems.

Background

In Ciba we have tried to apply TRIZ to chemical problems but have found it difficult to relate the 40 Principles to what happens in a chemical system. The main challenge we have experienced in applying TRIZ to chemistry is finding examples that can be used to explain the meaning of the 40 Principles in chemical terms. Most of the examples currently used are engineering systems that do not always have an obvious relevance to the molecular world.

In order to try to overcome this hurdle we have put together some illustrations based on chemistry and its applications rather than engineering. We have tried to use general chemical reactions or principles as far as possible, but coming from a pigment manufacturing background there are inevitably some examples which are specific to the colour industry. Full explanations of all examples given can be found in generally available chemical textbooks (see below) and most should be familiar to any chemist with a good general knowledge of the subject.

This list is not intended as an aid to the extension of TRIZ into chemistry, but rather as a teaching tool to help introduce TRIZ to chemists in terms they understand. We would be greatly interested in any other suggestions for illustrations, or any case studies involving chemical systems.

Chemical Illustrations of the 40 Principles of TRIZ

Principle Illustration

1 Segmentation

Separation into smaller parts

Mass Spectrometry – molecules broken down
determine structure

Synergist/hyperdispersant*

2 Extraction

Take out or separate something

Fractional distillation

Chromatography

Crystallisation

Soxhlet extraction of natural products or
additives.

3 Local Quality

Different parts of an object carry
out different functions

Surfactants – hydrophobic and hydrophilic parts

Block copolymers – pigment anchoring and

solvent compatible*

Directing groups – change the reactivity of different sites.

Charge transfer complexes.

4 Asymmetry

Introduce, or increase the degree of, asymmetry

Chiral centres – biologically active materials are often a particular stereoisomer

Surfactants

5 Combination (Consolidation) One pot reactions

Nitrocellulose – fuel and oxidant in the same molecule

High throughput synthesis/combinatorial chemistry/parallel synthesis. Used for synthesis/screening/crystallization

6 Universality

Use an object to perform several functions

Monomer used as solvent and reactant in UV inks

Urea used as solvent and source of nitrogen in Copper Phthalocyanine synthesis.

7 Nesting

Putting one thing inside another

Encapsulation

Inclusion compounds

Chelates – e.g. EDTA to mask transition metals

8 Counterweight

Compensate for the weight of an object

Loosely equating boiling point with weight: vacuum distillation or rotary evaporation.

9 Prior counteraction

Take action to prevent, or reduce, harmful effect

Drying of solvents for use in water sensitive reactions

Use of blocking groups to prevent reaction at particular sites

Use of secondary complexing agents in EDTA titration e.g. Zn will be precipitated at pH10 but we need this pH to titrate it with EDTA. Add Ammonium Chloride. The ammonia complex of Zn is soluble but does not interfere with the ZnEDTA chelate. (The NH₄CL also acts as a buffer – Principle 6 – Universality)

Use of protecting groups in organic synthesis
Reactions under argon/nitrogen

Low temperatures to prevent side reactions
Slow addition or defined order of addition to control side reactions
Dean Stark apparatus to remove water in condensation reaction

10 Prior action

Take action beforehand to ease an event
Back titration e.g. add excess of EDTA then back titrate the excess with Ca or Mg.
Adding UV stabilisers to prevent sun damage
Addition of seed crystals to control crystallisation
Crystal engineering by addition of additives, choice of solvent/conditions etc.

11 Cushion in advance

Prepare for things which may fail or go wrong
Explosion prevention system
Use of EDTA in fount solution to prevent precipitation of citrates/tartrates.
Bursting discs on pumps.
Cold finger traps when distilling

12 Equipotentiality

Avoid lifting or lowering an object
Catalyses and enzymes
Activating groups
Use of automated methods for addition e.g. syringe pumps

13 Inversion

Do it the other way round
Back titrations
Reverse chromatography to measure surface properties
Poisoning of crystal to prevent growth
Sublimation instead of crystallisation

14 Spheroidality

Replace linear with a curve or a sphere
Non-linear gradient for solvent mix in HPLC
Nano-tube graphite and fullerenes
Slowing coupling reaction toward the end to achieve a better end point

15 Dynamicity

Create systems which are able to cope with change and intrusions from the outside – separating parts, flexible connections etc.
Remove aromaticity, double bonds etc to make

a molecule more flexibly.
Increase chain lengths to increase flexibility
Use of plasticiser
PH and redox buffers

16 Partial, overdone or excessive action

Achieve more or less of the desired effect
Take reaction to 90% and then clean up rather than try to get 100%
Add excess of reactant to push an equilibrium in the desired direction.
Refluxing reaction mixture

17 Move to a new dimension Comb copolymers

Go upwards, sideways, around corners, rotate object, change viewpoint
Cross-linking polymers
Dendrimers
Branched rather than linear hydrocarbons
Multi-layer effect pigments
Cyclic rather than linear aliphatics

18 Mechanical vibration

Shaking, vibrating, sound waves, ultrasound
Sonochemistry
Photoinitiators, thermal initiators
IR. Spectroscopy

19 Periodic action

Pulsed action
Non-intrusive mixing

20 Continuity of useful action

Carry out actions without a break
Continuous vs batch production
Citric acid cycle
React and distil final product in same apparatus

21 Rushing through

Do things at high speed to reduce time for problems to occur
Kinetically controlled reactions
Drown out crystallisation to produce a thermodynamically unstable polymorph

22 Convert harm into benefit Use waste heat to pre-heat reactants

Recover and use by-products of a reaction
Immunisation

23 Feedback

Introduce. If it exists, change it
Buffered systems
pH controlled pump

Thin layer chromatography to monitor reaction progress.

Distil or otherwise remove side or by products to monitor progress of reaction

24 Mediator

Use an intermediary object to transfer or carry out an action

Photoinitiators

Steam heating

Synergists on pigment surface

Dispersant on pigment

Grignard reaction

Catalyst

Phase transfer catalyst

25 Self-service

Can your device do things for itself

Photochromic glass

26 Copying

Use a simple, cheap copy

Amplification reactions

Electron microscopy

Molecular modelling

27 Inexpensive short life (Dispose)

Replace expensive object with a

Disposable pipettes

cheap one Use excess of less reactive but cheaper raw material.

28 Replacement of a mechanical system

Replace a mechanical system with a field

Sonochemistry

Microwave reactions

Use of a radioactive source in a smoke detector

or a chemical reagent in a CO detector as

opposed to some mechanical means of measurement.

29 Use of pneumatic or hydraulic systems

Use pressure rise to detect a runaway reaction.

Use hydraulics for power when using flammable solvents

Filter press

30 Flexible films or thin membranes Vapour deposition of Cr to dissipate charge in

Scanning Electron Microscope

Interference colours

Surface treatments

Paints and inks

31 Use of porous materials Filtration

Zeolites

Chromatography e.g. GPC – small molecules enter pores and so take longer to elute

Osmosis

Crystal growth limited with a pore of say a zeolite

32 Changing the colour Titration indicators

Photochromic lenses

Carbonless copying

Thermochromic thermometers

33 Homogeneity

Increase? Decrease?

Block copolymers, comb copolymers

Replace solvent blend with single solvent with same solubility parameters

Phase transfer reactions

Is it necessary to have reagents in one phase?

e.g. solid state reactions avoid solvent or reaction between a solid and a liquid.

34 Rejecting and regenerating parts

When a part is used and no longer needed throw it away, restore it or recycle it

Catalysis

Silica gel for drying

Ammonia recovery

Recycling solvents e.g. recovery of toluene in gravure printing

35 Transforming physical or chemical states

Separation by distillation

Precipitation

Crystallisation

Drying/evaporation

Gas phase reactions

Sublimation

36 Phase transitions α to β Copper Phtalocyanine

Allotropes of sulphur

Synthesis of volatile derivatives for gas chromatography or gas phase reactions

37 Thermal expansion Explosives

38 Use of strong oxidisers Bleaches

Oxidising agents

Oxidation at electrodes

39 Inert environment N_2 blanket

Co-solvents or inert solvents

Vacuum

40 Composite materials Surfactants

Copolymers

Alloys

Nanocomposites – clays mixed with nylon give improved properties

* The term synergist/hyperdispersant is familiar to anyone working in the ink or surface coating industry. In principle, a dispersion of pigment particles in a liquid medium will tend to flocculate unless there is some stabilisation mechanism. In non-aqueous systems, this is achieved by adsorbing a solvent soluble chain onto the pigment surface. This creates a barrier which prevents particles from approaching close enough to interact. However, if the adsorbing chain is soluble, it will stay in solution and not adsorb onto the pigment. What is needed is an insoluble soluble surface treatment. The principle of segmentation is used by having a two part system. One part, the “synergist”, is insoluble and strongly adsorbs onto the pigment. This synergist contains polar groups. The dispersant consists of a soluble chain, with a polar end group. Overall, the dispersant is soluble in the medium, but the polar end group interacts strongly with the synergist and so is held close to the surface of the pigment. The soluble chain of the dispersant sticks out into the medium and gives a barrier to flocculation.

An alternative approach is to use ABA block co-polymers. The A blocks consist of solvent soluble chains, whereas the B block is insoluble. The B block will sit on the pigment surface and hold the A blocks in position to create the barrier.

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