Mathematics and Science in Schools in Sub-Saharan Africa
MATERIAL SCIENCE

METAL ALLOYS
Metals have many advantages

- Strong
- Malleable
- Conductors
- Shiny
Metal Customizing

Cold-working and heat treating metals changes the strength & flexibility of metals.
Disadvantages
An alloy is a metal composed of more than one element.
Alloy Metals

Engineering alloys include the cast-irons, steels, aluminum alloys, magnesium alloys, titanium alloys, nickel alloys, zinc alloys and copper alloys.
Desirable Mechanical Properties
In pure form, most metals are not very strong!

99% Pure Aluminum

Very Light, Very Weak

Aluminum Alloy Wheels

Light & Strong
Aluminum Alloys Make Flight Possible!

December 17, 1903
Wright Brothers

1st Aluminum Alloy Gas Powered Engine Block

Low Weight (<100 kg) High Power (~12HP)
Alloys Make Financial “Cents”!

Pre 1982 = 95% Copper

Post 1982 = 97.5% Zinc
Copper Coated

Coating = 10 micrometers
Lab: Floating Pennies
Corrosion Protection

- $S_2O_3^{2-}$
- SEC
- AFM
- Pit
- SS 304
- MnS
- Calc.$S_2O_3^{2-}$

Graph:
- Current Density [$\mu$A/cm$^2$]
- Potential [mV vs. SCE]
- Inclusion Dissolution
- $d_{exposed} = 100 \mu$m
Stainless Steel

Stainless steel is "stainless" because it is more resistant to rusting than ordinary steel.
Stainless steel’s chromium content is typically between 13-25%.
Stainless Steel

The thin layer of chromium on the outside actually forms chromium oxide.
Stainless Steel

If the metal is scratched, the oxide forms in the scratch, which make it “self-healing.”
Most silverware is not silver!

This keeps silverware looking nice and new.
First Alloy Made?

Bronze
Bronze is the traditional name for a broad range of alloys of copper. Bronze is composed of copper with tin as its main additive.
Earliest bronzes included arsenic which made it stronger than iron.
Modern Uses

- Ductility
- Machinability
- Corrosion Resistant
Pewter dates back at least 2,000 years to Roman times.

Ancient pewter contained about 70 percent tin and 30 percent lead.
Ancient pewter was often called black metal because it darkened greatly with age,

The lead readily leached out in contact with acidic foods.
Modern Safer Pewter

Today's functional pewter no longer contains lead.

Today’s pewter is between 85% and 99% tin, with the remainder consisting of 1-4% copper, acting as a hardener.
Some of today’s lower grades of pewter have the addition of lead for a bluish tint.
Brass
Brass is an alloy of copper and zinc.

Typically brass is more than 50 % copper.

Some types of brass are incorrectly called bronzes, despite their high zinc content.
Brass is a versatile manufacturing material because of its hardness and workability.

Some types of brass have other metals added to modify their properties.
Brass is corrosion resistant.
Other Modern Uses
Lab: Making An Alloy
Lab: Making An Alloy

Data Chart
The most used alloy?
Steel

World Steel Production, 1950–2004

Source: IISI
Steel is the common name for a large family of iron alloys which are easily malleable after the molten stage.
Steel

Steel is the worlds most recycled material.
Henry Bessemer

Generally credited with the invention of an efficient steelmaking process in 1856.
Steels are commonly made from limestone, iron ore & coal.
1 - Production of Molten Steel

- Limestone
- Iron Ore
- Coal
- Recycled Steel - Scrap

Sinter Plant - Sinter
Coke Ovens - Coke
Blast Furnace - Molten Iron
Electric Arc Furnace
Basic Oxygen Vessel
Secondary Steelmaking

Molten Steel

Offcuts from various processes & scrap

Click this button to go to the next page
Effects of Carbon

How hard steel is depends on the how much carbon is inside.
Effects of Carbon

Hardness and tensile strength increases as carbon content increases up to about 0.85% C!
Effects of Carbon

The scissors’ steel contains ~20% times the carbon as the steel used in a soda can!
Effects of Carbon

Ductility and weldability decrease with increasing carbon.

Figure 1. Beam specimens
Types of Steel Alloys

There are more than 3500 different grades of steel with many different physical, chemical & chemical properties.
Carbon Steels
Chromium is commonly added to steel to increase corrosion resistance and oxidation resistance.
Chromium Steel

Chromium is commonly added to steel to increase corrosion hardness or to improve high temperature strength.
High Chromium Steel (17% Cr)

*Used for pump shafts, values and fittings subject to high temperatures and pressure.*

*Unsuitable for acidic conditions.*
Titanium is used to retard grain growth and thus improve toughness.
Titanium Steel

Titanium causes sulfide inclusions to be globular rather than elongated thus improving toughness and ductility in transverse bending.
Nichrome is an alloy of nickel and chromium.
Nichrome

This alloy has a very high melting point and high electrical resistance.
In 1965, the first of a series of metal alloys of nickel and titanium was produced by the Naval Ordnance Laboratory.
NITINOL’s Unique Properties

10X Elasticity of Stainless Steel
NITINOL’s Unique Properties

It “remembers” its shape!
Lab: Memory Metal
NITINOL WIRE

Nitinol wire

Bend to any shape when cold

Drop into cold water

Heat water and Nitinol wire "zips" back to its original shape at a "characteristic" temperature
This "smart" property is the result of the substance's ability to undergo a phase change - a kind of atomic ballet in which atoms in the solid subtly shift their positions in response to a stimulus like a change in temperature.
The sample recovers its original shape as its temperature is raised above the temperature corresponding to the phase change.
This temperature may be tuned by varying the ratio of nickel to titanium atoms in the solid by a few percent relative to a 1:1 ratio.
Commercial Applications
Medical Applications

Nitinol can be designed to apply constant force or stress over a variety of shapes.
Medical Applications

Nitinol can be designed to apply constant force or stress over a variety of shapes.
Stents

balloon stent in position across lesion

sheath retracted

expansion of balloon & stent

stent scaffolds artery after removal of balloon
More stable and less corrosive that stainless steel.

MRI compatible.
NITINOL’s Unique Properties

“Muscle” Metal
NITINOL’s Unique Properties

“Muscle” Metal
NITINOL’s Unique Properties
NITINOL’s Unique Properties
Home Applications
"Out of This World" Applications

Measuring Dust on Mars
Metal Alloy Implants

Crown

Gum

Tooth Root

Dental Implant

Jawbone

Bone forms biological bond with dental implants.
Metal Alloy Implants

Titanium alloy implant fuses with the jawbone.
Metal Alloy Implants

Bone screws and plates made of surgical steel + titanium alloys.
Metal Alloy Implants

Broken fourth metacarpal of gymnast repaired with a plate and screws. Bones of hand, with gymnast hand gripping bar.
Metal Alloy Implants
Super alloys are metallic alloys used for long service at elevated temperatures above 650°C (1,200°F).
Super Alloys

TENSION TEST AT 800°C

ELONGATION (%)

Hf (wt%)
Super Alloys

The common super alloys are based on nickel, cobalt or iron.
Super Alloys

Their versatility stems from the fact that they combine this high strength with good low-temperature ductility and excellent surface stability.
The creep life of the blades is limited by the grain boundaries.
Liquid Metal

Liquid Metal alloys were conceived in 1992, as a result of a project funded by the California Institute of Technology (CalTech), NASA, and the U.S. Department of Energy.
Liquid Metal

More than twice as strong as titanium & steel!
Liquid Metal

*Liquid Metal doesn't rust and it can be cast like plastic and honed to an edge as sharp as glass.*
Its properties translate into a surface that is scratch, dent, and corrosion resistant, and at the same time provides a high gloss that can be polished to a luxurious jeweler’s finish.
Lithium Monobororide (LiB)
Super Battery Alloys
Superconductive Alloys

magnetoplumbite
\( \text{SrGa}_4\text{Cr}_8\text{O}_{19} \)

Local Moment
AFM

Frustration

QC2:local

QC1:SDW

Small FS

AFL

Kondo coupling

Large FS + SDW

(1-x) holes

(1+x) electrons