Mathematics and Science in Schools in Sub-Saharan Africa
Material Science

Biodegradable

POLYMERS
Each year, we produce millions of tons of garbage that are disposed of in landfills.
I.T.’s Superhighway Trash Yields A Super Highway Asphalt!

Discarded electronic hardware can be recycled into an additive that makes super-strong asphalt paving material for real highways.
The new material makes high-performance paving material asphalt that is cheaper, longer lasting, and more environmentally friendly than conventional asphalt.
Recycling Summary

- Asphalt Pavement: 80.3 million tons
- Scrap Steel: 70.0 million tons
- Paper: 34.9 million tons
- Compost: 12.1 million tons
- Metals: 6.5 million tons
- Concrete Pavement: 3.3 million tons
- Glass: 2.9 million tons
- Plastics: 1.1 million tons

(million tons)
Plastic Recycle Codes

1. PETE
2. HDPE
3. V
4. LDPE
5. PP
6. PS
7. OTHER
Polyethylene Terephthalate is inexpensive, lightweight and easy to recycle.

PET plastic is safe for single-use only!
High Density Polyethylene is a versatile plastic with many uses.

**HDPE plastic is safe for multiple-use!**
Polyvinyl Chloride is tough and weathers well.

PVC plastic contains chlorine, a dangerous toxin!
Low Density Polyethylene is a flexible plastic with many applications.

LDPE plastic is safe for multiple-use!
Polypropylene has a high melting point.

PP plastic is safe for multiple-use!
PS can be made into rigid or foam products.

Polystyrene plastic is safe for multiple-use!
Lab: Second Time Around
Lab: Second Time Around

Info Box

<table>
<thead>
<tr>
<th>Solution</th>
<th>Density</th>
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</thead>
<tbody>
<tr>
<td>52% Ethanol</td>
<td>0.911</td>
</tr>
<tr>
<td>38% Ethanol</td>
<td>0.941</td>
</tr>
<tr>
<td>24% Ethanol</td>
<td>0.965</td>
</tr>
<tr>
<td>6% CaCl₂</td>
<td>1.0505</td>
</tr>
<tr>
<td>32% CaCl₂</td>
<td>1.306</td>
</tr>
<tr>
<td>40% CaCl₂</td>
<td>1.398</td>
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</tbody>
</table>
# Lab: Second Time Around

## Data Chart

<table>
<thead>
<tr>
<th>Sample #</th>
<th>Density</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
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<tr>
<td>2</td>
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<tr>
<td>4</td>
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<td>5</td>
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<td>6</td>
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</tbody>
</table>
Lab: Second Time Around

Analysis

<table>
<thead>
<tr>
<th>Sample</th>
<th>Identity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</tbody>
</table>
Biodegradables

Materials that are broken down by natural processes into non-toxic, reusable substances.
Almost all biodegradable materials are made of polymers.
Brandenberger succeeded in producing the first biodegradable plastic from the plant-derived structural polysaccharide cellulose.
Cellophane

Ironically, at that time Cellophane's inherent biodegradability hampered its suitability for certain applications and it was quickly superseded by more conventional and durable plastics.
Biodegradable Polymers
Biodegradable Polymers

- Polycaprolactone
- Polyvinyl alcohol
- Polyhydroxybutyrate
- Polylactic acid
- Starch, $\alpha$ 1,4 linkage
- Cellulose, $\beta$ 1,4 linkage
Polymerized Lactic Acid (PLA)

Since only ~14% of plastic water bottles are recycled, a new plastic resin derived from corn byproducts (PLA) is now being used for plastic bottles.
Polymerized Lactic Acid (PLA)

PLA is a renewable natural resource that is commercially compostable in ~75 days and require 30% less energy & 50% less CO₂ to produce than conventional plastic.
Most polymers are not biodegradable!

Conventional polyethylene products can take longer than 100 years to degrade!
<table>
<thead>
<tr>
<th>Product</th>
<th>Time to biodegrade</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cotton Rags</td>
<td>1-5 months</td>
</tr>
<tr>
<td>Paper</td>
<td>2-5 months</td>
</tr>
<tr>
<td>Rope</td>
<td>3-14 months</td>
</tr>
<tr>
<td>Orange peels</td>
<td>6 months</td>
</tr>
<tr>
<td>Wool socks</td>
<td>1 to 5 years</td>
</tr>
<tr>
<td>Cigarette filters</td>
<td>1 to 12 years</td>
</tr>
<tr>
<td>Plastic coated paper milk cartons</td>
<td>5 years</td>
</tr>
<tr>
<td>Leather shoes</td>
<td>25 to 40 years</td>
</tr>
<tr>
<td>Nylon fabric</td>
<td>30 to 40 years</td>
</tr>
<tr>
<td>Plastic bags</td>
<td>10-20 years</td>
</tr>
<tr>
<td>Plastic holder rings (6-Pack)</td>
<td>450 years</td>
</tr>
<tr>
<td>Glass</td>
<td>1 million years</td>
</tr>
<tr>
<td>Plastic bottles</td>
<td>Never</td>
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</tbody>
</table>
Symphony Environmental has produced new additive technology to reduce the plastic to carbon dioxide and water in just a few weeks.
Improving Biodegradability
Grafting allows a composite material made from two or more different components to function as a single material.
Grafting

The goal is to combine the good physical properties of a synthetic polymer with a biodegradable partner.

\[
\text{Glycerol + Starch-OH} \xrightarrow{\text{AlEt}_3 \text{ catalyst}} \text{Plasticised starch-O-AlEt}_3 + \text{C}_2\text{H}_6
\]

(\text{i}) Preparation of initiator

\[
\text{Plasticised starch-O-AlEt}_3 \xrightarrow{\text{CL monomer} \ H_2\text{O}} \text{Plasticised starch-O-} \frac{\text{O}}{\text{C-} \ (\text{CH}_2)_x \ -\text{O-H}} \]

\text{CL = caprolactone} \quad (\text{ii}) \text{ Ring opening polymerisation} \quad x = 4 \text{ or } 5
Biodegradable Plastic Bags
A biodegradable polymer does not generally sell simply because it is biodegradable, it must compete as a material on the basis of its own price/property characteristics, with biodegradability an added bonus.
Biodegradable Packing
Lab: Biodegradable Packing
# Lab: Biodegradable Packing

**Data Chart**

<table>
<thead>
<tr>
<th></th>
<th>Biodegradable</th>
<th>Non-Biodegradable</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Stress</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Strain</strong></td>
<td></td>
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<tr>
<td><strong>Strain</strong></td>
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</table>
What is the Process of Biodegradability?

Polymer Degradation
Polymer Degradation

Any change of the polymer properties relative to the initial, desirable properties is called degradation.
Type I

X represents the labile backbone bonds

Type II

A represents hydrophobic side groups
B represents hydrophilic side groups

Type III

Y represents the crosslinks
Polymer Degradation Factors
Enzymes

A protein functioning as a biochemical catalyst in a living organism.

How enzymes break down food into nutrients
Food

Diagram of the digestive system:
- Esophagus
- Liver
- Gall Bladder
- Stomach
- Pancreas
- Large Intestine
- Small Intestine
- Appendix
- Rectum

Chemical structure on the right:
\[ R - C_\alpha - O - H \]

H - N
H

CO
Microbial Action

E. Coli
Microbial Action

Remains of dead organisms are decomposed by certain bacteria, fungi and algae.
SUMAR

A specially made latex rubber that enables protein degradation by bacterial action that is controlled chemically.
Chemical Structure
Surface Area

Surface Area $\propto (1 / \text{Size})$

<table>
<thead>
<tr>
<th>Edge (cm)</th>
<th>Number of cubes</th>
<th>Surface area (cm$^2$/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td>0.0001 (1 (\mu)m)</td>
<td>10$^{12}$ (1 trillion)</td>
<td>60,000 (6 (m^2)/g)</td>
</tr>
</tbody>
</table>

M. Hubbe

The amount of an object exposed to the environment.
Lab: Surface Area vs. Size & Shape

Interactive
<table>
<thead>
<tr>
<th>Geometric Shape(s)</th>
<th>Total Volume (cm$^3$)</th>
<th>Total Exposed Surface Area (cm$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solid Cube</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8 Smaller Cubes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8 Plate-Like Particles</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Density

Weight-Strength-Mass Reduction Rates
Ultraviolet rays cause some polymers to degrade.
Temperature
Temperature vs. Degradation

[Graph showing the relationship between Temperature and Degradation for polymer sample mass and pressure.]
Presence of Water
Mineral fillers today are widely used in plastic production as degradable fillers that improve performance and reduce costs.
pH

- lemon juice pH 2.0
- wine pH 4.0
- rain pH 5.5
- human blood pH 7.5
- baking soda pH 8.5
- detergent pH 10.0
- bleach pH 12.5

Optimal range for most life: pH 6.5-8.2
Biodegradability Advances
Biodegradable Sutures

Eliminates the need for a second operation to remove the sutures.
Orthopedic pins and screws are now being made of strong biodegradable materials.
Trabecular Bone

Polymer Scaffold
In 2005, medical researchers were shocked to discover that virtually all human embryonic stem cell lines were contaminated.
Animal byproducts used to line Petri dishes had left traces on the human cells.

If those cells had been implanted in a human body they likely would have been rejected by the patient's immune system.
Scientists have now built a three-dimensional scaffold out of a natural material that mimics the binding sites for stem cells, allowing the cells to reproduce on a clean, biodegradable structure.
Researchers seeded the scaffold with 500,000 embryonic stem cells, and after 21 days the scaffold was completely saturated. These results show that human embryonic stem cells grow and multiply readily on the structure.
Self-Healing Biodegradable Polymer

Researchers in The Netherlands are reporting development of thermally self-healing polymeric materials for use in the first easy-to-recycle computer circuit boards.
The new type of thermosetting plastic that can be melted and remolded without losing its original heat-resistance and strength.

Tests show you could melt granules of the "self-healing" polymer and reform them into uniform, rigid plastic bars many times.
Drug Delivery System

One area of intense research activity has been the use of biocompatible polymers for controlled drug delivery.
Drug Delivery System

Biocompatible polymer release rates can be determined by the design of the system and are nearly independent of environmental conditions.
Localized delivery lowers the systemic drug level, reduces the need for follow-up care, preserves medications that are rapidly destroyed by the body, and increases patient comfort.
The goal of the controlled release devices is to maintain the drug in the desired therapeutic range with just a single dose.
Drug Delivery Systems

Gelatin has been the most used biocompatible polymer for controlled drug delivery.
Gelatin is a vitreous, brittle solid that is faintly yellow to white and nearly tasteless and odorless.
Gelatin contains 84-90% protein, 1-2% mineral salts and 8-15% water.
Lab: Making a Gel
Lab: Gel Dissolve Rate
Lab: Gel Dissolve Rate

*Data Chart*

<table>
<thead>
<tr>
<th># of Caps</th>
<th>Dissolve Time (s)</th>
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<tbody>
<tr>
<td>8</td>
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<tr>
<td>12</td>
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<tr>
<td>16</td>
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<td>24</td>
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<td>28</td>
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<tr>
<td>32</td>
<td></td>
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</tbody>
</table>
The challenge facing drug delivery system gel is can it smuggle its contents past the stomach and slowly release the drug into the blood later on where its needed!
pH = 1.5 to 3.5
Food spends between 30 minutes and 2 hours in the stomach!
Fig. 2 Resolvability of Probiotic GFR Capsules in low pH solution (pH 2.5)

- pH 2.5, at start
- pH 2.5, after 60 min
- pH 2.5, after 120 min
- pH 2.5, after 240 min
Fig. 3 Resolvability of Probiotic GFR Capsules in neutral pH solution (pH 6.5)

- pH 6.5, at start
- pH 6.5, after 30 min
- pH 6.5, after 60 min
- pH 6.5, after 120 min
Stomach-proof gel hints at jab-free diabetes treatment

Insulin-loaded gel was able to cope with acidic stomach-like conditions for an hour, but when in less acidic conditions like those found in the intestines, the gel swelled and release its payload.
Lab: Gel in Acid
Lab: Gel in Acid

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Biodegradability Advances
Electrical Conducting Nanotubes

Nanotubes made of a polymer that conducts electricity will release drug in response to an electrical signal.
Deposited nanotubes on a microelectrode could yield implantable drug delivery devices capable of treating tumors repeatedly on a programmed time schedule.
Electrical Conducting Nanotubes

These would allow patients or their physicians to determine exactly when drugs are delivered, and in what quantities.