HARDWARE

The system described above operates on a Digital Equipment Corp. PDP 11/70 with the Resource Sharing Time Sharing operating system. Software has been coded in BASIC-PLUS. Data entry is achieved through use of an Ann Arbor cathode ray tube using full screen data entry. Searching may be carried out at any terminal compatible with the PDP 11/70. A previous generation of this system was developed on an IBM 370/158, with batch mode data entry and on-line search.

CONCLUSION

Dow has developed an on-line interactive data storage and retrieval system for polymer products. Queries to the system may retrieve information for a particular trade name or family of trade names, or any group of substances with certain substructure, composition and/or property criteria. The system will provide the polymer scientist, engineer, or salesman with rapid access to current data for the specific needs of their particular occupation. The system will also serve as a prototype for other small in-house data management systems.

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A Classification System for Polymer Literature in an Industrial Environment†

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Polymer science and technology has evolved over the past 35 years into a significant and fast-growing literature with a unique nomenclature and language, and as an extension rather than a part or subclass of physics, chemistry, and engineering. A book classification system is described that treats polymer science and technology as a major class oriented to the information needs of polymer scientists and engineers in an industrial environment.

Classification is a process of differentiation in which objects or ideas are brought together by similarities and separated by differences. Languages are replete with classificatory concepts: solids/liquids/gases; plants/animals; land/water; and night/day, to name a few. Languages rich in synonyms and antonyms have enabled scientists to observe and study nature and to think with a great spectrum of similarities and differences.

Classification schemes have been of great importance in the history of knowledge and education. An outstanding example of a classification system was the family–genus–species concept that Linnaeus introduced in 1738, and which marks the beginning of the systematization of botany. The outstanding example of a classification system in chemistry was Mendeleev's introduction of the periodic table in 1869. This paradigm in chemistry pointed out not only potential errors of existing information but predicted the discovery of new elements and their properties. The periodic table motivated and advanced research and it remains a powerful teaching aid.[11,12]

The classification of knowledge has played an important role in how documents are arranged in libraries, especially large libraries. Well into the 19th century, the majority of libraries arranged books alphabetically by author or by title, size, color, or accession. A few libraries employed a classification system based on academic fields of study, and some even used a decimal system—for the shelves, not the books. We are indebted to Melvil Dewey for the Decimal Classification System which he introduced in 1876 for the arrangement of documents in libraries and which quickly was adopted as such or modified by many libraries.

The major library book classification systems used today are: Dewey; the Universal Decimal Classification or UDC, which is a modified Dewey; and the Library of Congress or LC.[4,5,9]

Table I. Some Principal Classes in the Dewey System

	500	Pure Science
	540	Chemistry, Crystallography, Mineralogy
	541	Physical Chemistry
	542	Apparatus and Equipment
	543	Analytical Chemistry
	546	Inorganic Chemistry
	547	Organic Chemistry
2	547.013	Polymerization: Organic Chemistry
3	547.92	Special fields of organic chemistry
		starch
		cellulose
		high polymers
		rubber
		synthetic resins
	600	Applied Science
4	660.28	Chemical Engineering
	661	Industrial Chemicals
	668	Other Organic Chemical Materials and Products
	668.4	Plastics Industries, Resins, Gums
	668.422	Condensation Plastics, e.g., Phenolics
	668.423	Linear Polymer Plastics (except fibers), e.g., polyethylene
1	668.44	Plastics from cellulose
	677	Textile and Other Fiber Manufacturers
	677.46	Rayon
	678	Rubber
	678.3	Natural and Synthetic Rubber
	678.7	Elastomers
	678.72	Synthetic Rubber
	678.722	Polymerization: Synthetic Rubber

See Table V for identification of 1, 2, 3, and 4

Libraries using the Dewey system adhere to the classes shown in Table I.

Libraries using the UDC system arrange books according to the classes shown in Table II.

Polymerization in UDC is assigned the number 542.952.6

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Table II. Some Principal Classes in the UDC System

5	Natural Sciences
54	Chemistry
543	Analytical Chemistry
547	Organic Chemistry
547.313.2	Ethylene
547.391.1	Acrylic Acid
6	Applied Sciences
66	Chemical Technology
67	Manufacturers
677	Textiles
677.4	Synthetic Fibers - Rayon
678	Macromolecular Materials - Rubber and Plastics
678.01:53	Physical Properties
678.01:536	Thermal Properties
678.06	Applications
678.06:621	Engineering
678.06:621.3	Electrical
678.4	Rubber and Natural Macromolecules - C and H only
678.5	Plastics based on Cellulose, Proteins, etc.
678.542	Cellulose
678.544	Cellulose Esters
678.546	Cellulose Ethers
678.6	Polycondensates, Resins, Fibers, etc.
678.632	Phenol-Aldehyde Polycondensates
678.7	Synthetic Rubbers, Resins, etc.
678.742.2	Polyethylene
678.742.3	Polypropylene
678.743.22	Poly(vinyl chloride)
678.744.322	Poly(acrylic acid)
678.746.22	Polystyrene
678.762.2	Polybutadiene

in which 542 is experimental chemistry. A book covering both cellulose chemistry and cellulose plastics is assigned the number 547.458.8 + 678.54.

Polymer books in libraries using the Library of Congress classification system would be dispersed under the classes shown in Table III.

The three major library classification systems are based primarily on traditional disciplines, i.e., preexisting knowledge, and reflect pretty much the spectrum of academic curricula of major universities, which may or may not be congruent with the real world of knowledge and practice. We do know that none has been able to keep pace with the advances of science and the changing nature of technology, and the dichotomization of science into "pure" and "applied" is anachronistic to newer disciplines, such as polymer science.

Chronologically, polymer science began in 1826 when Faraday[6] reported the empirical formula of natural rubber to be C_5H_8. In 1839, Simon[10] observed that styrene, on heating, yields a solid transparent product. The word polymerization was introduced in the literature in 1866.[3] In 1872, Baumann[2] synthesized poly(vinyl chloride),[3] Baeyer[1] reported the preparation of phenolic resins, and, in 1880, Fitig and Englehorn[7] polymerized methacrylic acid. Subsequently, chemists synthesized a variety of polymers, but the understanding of the polymerization process and the structure of polymers did not begin until the 1920s, and especially in the 1930s with the work of W. Carothers on polyamides and polyesters and in the 1950s with the work of K. Ziegler on the polymerization of α-olefins.

Polymer technology preceded the science by many decades. Most of the technological developments of the 19th century and early 20th century were associated with cellulose and phenolic resins. The first commercial plastic was celluloid, i.e., cellulose nitrate plasticized with camphor, which was produced by the Celluloid Corp. in 1872. Rayon began the synthetic textile industry in the 19th century. In the early 1900s, new plastics of cellulose derivates, e.g., cellulose acetate and ethylcellulose, initiated a major new industry, the custom molding of plastics. By 1950, the more important commercial

Table III. Some Principal Classes in the Library of Congress System

	Q	Science
	QC	Physics
	QD	Chemistry
	QD1-69	General
	QD71-145	Analytical
	QD151-199	Inorganic
3	QD241-449	Organic
2	QD453-655	Physical and Theoretical
	QD7	Nomenclature
	QD281.P6	Polymerization
	QD325	Starch, Cellulose
	QD409	Organometal Compounds
	QD419	Gums and Resins
	T	Technology
	T175	Industrial Research
	TA	Engineering
4	TA401-498	Materials of Engineering
	TJ	Mechanical Engineering
	TP	Chemical Technology
	TP155	Chemical Engineering
	TP977-982	Gums and Resins, Naval Stores
	TP986	Plastic Materials
	TP986.A5	Special Plastics
1	TP986.A5.B3	Bakelite

See Table V for identification of 1, 2, 3, and 4

polymers included acrylics, cellulosics, phenolics, silicones, rubbers, polyamides, polyesters, and high-pressure polyethylene. Over 40 major classes of polymers are commercially produced today. In 1977, about 35 billion pounds of plastics was produced in 325 plants in the United States by 125 companies. The major output, however, is accounted for by 40 companies. There are over 4000 plastic fabricators in the United States.[8]

Concomitant with the rapid growth of the plastic, fiber, and film industries over the past 30 years was the increasing number of scientists and engineers in the industrial sector who made this rapid growth possible through their R&D work. Until relatively recently, the educational background of these scientists and engineers was in physics, physical chemistry, organic chemistry, analytical chemistry, chemical engineering, or mechanical engineering. It was not until the 1940s that an American university introduced the first curriculum in polymer science. Today, there are only 30 some colleges and universities that offer a reasonably full curriculum in polymer science, which is about 1.5% of the approximately 2000 institutions that grant degrees in chemistry.

Of the 28 divisions of the American Chemical Society, five are concerned with some phase of polymer science and technology, and approximately 20% of the ACS membership is working as polymer scientists or engineers. In terms of industrial R&D expenditures, polymer science is second to only the pharmaceutical/medical sciences. More than one-half of the R&D scientists and engineers at the Hercules Research Center are involved in polymer science and technology. From our perspective, polymer science and technology deserves the status of a major discipline of chemistry, not as a subclass or subsubclass of organic chemistry, physics, physical chemistry, or applied science.

In an industrial chemical library, it is not sufficient nor efficient to single out one class of documents as a service to only one unit of the R&D environment. It is essential to serve all units of the environment, and to serve these units in a frame of reference that is congruent or in harmony with the R&D assignments considered to be important. It was apparent that the three primary library classification systems could not be modified effectively to serve our needs. This does not mean,

Table IV. The Hercules Research Center Library Book Classification

General References
- 1.000 Directories
- 1.010 Publishers
- 1.020 People (Who's Who, Memberships, etc.)
- 1.030 Societies and Institutions
- 1.040 Colleges and Universities
- 1.050 Laboratories
- 1.060 Manufacturers
- 1.070 Governmental Agencies
- 1.100 Dictionaries
- 1.200 Encyclopedias, Compendia - General
- 1.210 Encyclopedias, Compendia - Inorganic
- 1.220 Encyclopedias, Compendia - Organic
- 1.300 Encyclopedias, Compendia - Technology
- 1.330 Handbooks - General
- 1.340 Handbooks - Physical Constants

History and Philosophy of Science, Industrial Functions
- 1.500 History and Philosophy of Science
- 1.600 Industrial Functions
  - 1.600 Industrial Organizations, Administration, etc.
  - 1.630 Communications - Report Writing, etc.
  - 1.640 Information Science, Library Science
  - 1.650 Patents, Law, etc.
  - 1.660 Market Research

Medical, Toxicology, Life Sciences
- 1.700

Engineering, Mathematics, Physics
- 2.000 Engineering Other Than Chemical Engineering
- 2.200 Chemical Engineering
- 3.000 Mathematics and Computer Science
- 3.500 Physics

Physical Chemistry
- 4.000 General
- 4.800 Photochemistry

Analytical Chemistry
- 5.000 General
- 5.100 Quantitative
- 5.200 Technical Analysis
- 5.400 Natural Products
  - 5.420 Cellulose
  - 5.430 Rosin, Resin Acids
  - 5.435 Gums
- 5.600 Monomers, Polymers, Plastics

Inorganic Chemistry
- 6.000 General

Organic Chemistry
- 7.000 General

Polymer Chemistry and Technology
- 8.000 Compendia
- 8.010 General Books
- 8.015 Biopolymers
- 8.020 Inorganic Polymers
- 8.050 Polymerization
- 8.060 Telomerization
- 8.070 Cross-linking (Radiation, Grafting)
- 8.080 Polyelectrolytes
- 8.100 Thermoplastic Polymers
  - 8.100 General
  - (3) → 8.110 Polyethylene
  - 8.111 Polypropylene
  - 8.112 Polybutene
  - (1), (2) → 8.120 Polyethers
  - 8.130 Polystyrene
  - etc.
- 8.200 Thermosetting Resins
  - 8.200 General
  - 8.210 Phenolics
  - etc.
- 8.300 Cellulosics
  - 8.300 Compendia
  - 8.310 General Books
  - 8.320 Properties
  - 8.330 Cellulose Esters
    - 8.331 Cellulose Acetate
  - 8.340 Cellulose Ethers
- 8.400 Rubber
  - 8.400 Compendia
  - 8.405 Dictionaries, Glossaries
  - 8.410 General Books
  - 8.450 Properties
- 8.500 Other Natural Polymers
- 8.800 Plastics and Plastic Technology
  - 8.800 General
  - 8.830 Processing (Molding, Extrusion)
  - 8.835 Foamed Products
  - 8.845 Encapsulation
  - 8.850 Reinforced Plastics and Composites
- (4) → 8.900 Properties of Polymers and Plastics

Use and Applications of Chemicals
- 9.000 General, e.g., Formularies
- 9.020 Solvents
- 9.022 Plasticizers
- 9.030 Protective Coatings
- 9.090 Printing Inks
- 9.100 Adhesives
- 9.140 Detergents, Soaps
- 9.180 Dyes
- 9.200 Textiles
  - 9.220 Cotton
  - 9.230 Rayon
  - 9.250 Nonwovens
  - 9.260 Processing
  - 9.270 Properties
  - 9.280 Testing
- 9.300 Paper Technology
- 9.400 Food Technology
- 9.500 Agricultural Chemistry
  - 9.500 Botany
  - 9.520 Fertilizers
  - 9.540 Plant Growth Chemicals
  - 9.545 Weed Control
  - 9.550 Entomology
  - 9.570 Insecticides, Fungicides
- 9.600 Explosives and Rocket Technology
- 9.750 Petroleum Technology

Annuals, Conferences, Meeting Abstracts
- 10.000 Annual Reports and Reviews
- 10.100 Proceedings
- 10.200 Meeting Abstracts

See Table V for identification of (1), (2), (3), and (4)

however, that we could not derive beneficial ideas from these systems, and to the degree that we could, we did.

Inasmuch as the number of books in the Research Center Library was in the thousands (over 10 000), rather than in the hundreds of thousands or in the millions, our initial evaluation and study indicated that we needed no more than ten cardinal numbers, 1–10, to cover the spectrum of classes relevant to our R&D organization. We liked the decimal concept, but decided not to go more than three places beyond the decimal. Thus, 99% of our books have a four-digit call number.

Table V. Four Books Classified by Three Systems

1. "Poly(ethylene Oxide)", by F. E. Bailey, Jr., and J. V. Koleski, Academic Press, 1976
   - L.C. : TP1180.P653B34 } Applied Science
   - Dewey : 668.4'234
   - Hercules: 8.120
2. "Polyethers", Edited by E. J. Vandenberg, ACS Symp. Series 6, 1975
   - L.C. : QD380.P63 } Pure Science
   - Dewey : 547'.84
   - Hercules: 8.120
3. "Cationic Polymerization of Olefins: A Critical Inventory" by J. P. Kennedy, Wiley-Interscience, 1975
   - L.C. : QD305.H7K38
   - Dewey : 547'.8432'234
   - Hercules: 8.110
4. "Polymer Materials Science", by J. Schultz, Prentice-Hall, 1974
   - L.C. : TA455.P58S36 } Materials of Engineering
   - Dewey : 620.1'92
   - Hercules: 8.900

From observations on how our scientists and engineers used the library books, conversations with them on how they would like the books arranged, consultations with key scientists and engineers on how they viewed our categories of interests, and knowledge of the R&D organization, we designed and established a new book classification system. An abridgement of the classification system (the total schedule requires 24 typewritten pages) is shown in Table IV, with emphasis on the polymer chemistry and technology class which is listed in some detail, but not completely.

In addition to the emphasis placed on polymer science and technology, the classification system also shows a strong orientation to the large number of books on the uses and applications of chemicals. This 9.000 class is basically a categorization of the chemical industry and the industries the chemical industry serves. The 9.500 subclass illustrates the uniqueness of the classification system for a well-defined group of scientists whose assignments require a body of books encompassing botany, entomology, fertilizers, herbicides, insecticides, fungicides, etc. These books were purchased for this group, and it is to the advantage of the scientists in the group to be able to browse in one section of the library for just those books that are specifically relevant to their assignments.

From the users' viewpoint, browsability among the books in a library is their primary requirement. They expect to see the books they are interested in, or potentially interested in, to be together, not scattered throughout the stacks. When the book they are looking for is not on the shelf, they want to be able to assume that it is out on loan, not shelved in some other section of the library. They prefer to consult the book catalog only as the last resort.

Table V lists the call numbers of four recently published books by the LC, Dewey, and Hercules classification systems. The LC and Dewey call numbers were taken from the copyright page of each book.

There is a great difference in these call numbers in terms of memory retention. Only one, the Hercules call number, is sufficiently short for one to retain going from the book catalog to the stack section. Both the LC and Dewey call numbers are beyond reasonable memory retention.

Most strikingly, these four examples illustrate the dispersion of polymer books by the LC and Dewey call numbers. Although the book "Poly(ethylene oxide)" covers the oligomers and polymers of ethylene glycol by condensation, its primary importance lies in the coverage of linear polymers of ethylene oxide, and this is the main coverage of the book "Polyethers". It is a disservice to the literature of polymer chemistry to separate these two books between applied and pure science. It is to be noted that these two books are next to each other, with the same call number, in the Hercules Research Center Library. There are only a relatively few books which have been published so far on polyethers, such as from glycols, epoxides, and phenols [poly(phenylene oxides)]. I think polymer chemists would like to see these books on the same shelf.

Books on the process of polymerization in the LC and Dewey systems are classified in the *reaction* subsubclass of the subclass *organic* chemistry of the class *pure science*. Thus the book "Cationic Polymerization of Olefins. . ." was given the call number QD305 in LC and 547 in Dewey. If polymerization was the key coverage of the book, we would have assigned the call number 8.050, but the primary emphasis is on olefin polymers, and specifically on polyethylene, and accordingly it was assigned the call number 8.110.

The book "Polymer Materials Science" was categorized as *Materials of Engineering* (*nonmetal*), a subsubclass of *general engineering* under the class Technology in both the LC and Dewey systems. We placed it under *properties of polymers and plastics* in the *polymer chemistry and technology class*.

Because science and technology are subject to relatively rapid and sometimes radical changes, a book classification system for a special library serving an R&D function in a chemical industrial environment must possess a degree of flexibility. At least the system should be sufficiently flexible to handle a new discipline of science or a new area of importance to the environment without a major change in the basic philosophy of the classification schedule, i.e., without the need to reclassify the thousands of books in the library, which is a very expensive endeavor. Each industrial environment has its own unique flavor, the way it recognizes and solves problems, and the scope of knowledge and experiences of the R&D staff. A book classification system that relates to the uniqueness of the environment is an important R&D tool.

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