Gallium Arsenide

Electron mobility inside it is about five times higher than in silicon hence a shorter switching time and consequently higher information processing speed. Because of its non-existent light-emitting properties, silicon is not suitable for making optical components (like light-emitting diodes, semiconductor lasers or light modulators), unlike gallium arsenide. (On the other hand, silicon is the basic element of photodetectors). Gallium arsenide has better insulating properties than silicon and this delays micro-circuit breakdown.

The frequency limit for the use of gallium arsenide devices is in the region of 60 GHz against a few GHz in he case of silicon, thus opening up the hyperfrequency market to gallium arsenide (in particular, for reception of satellite signals which are carried by waves in this frequency range).

The energy consumption of gallium arsenide is lower than that of silicon (about one-tenth), leading to far less heating in integrated circuits. Moreover, the range of operating temperatures is far wider than in the case of silicon (350°C as against 200°C). These properties would lead GaAs winning hand down if it were not for the very developed technology of silicon-based devices. But as usual, special niches will serve as incubator rooms for the subsequent dispersal of technology matured there. Some important lines of application can be:

Integrated circuits. Gallium arsenide complements silicon in this application being superior to silicon in certain of its electronic properties; its higher carrier mobility and drift velocity enable gallium arsenide devices to operate faster and to dissipate less power than their silicon equivalents. However, there are high price penalties to be paid for this improved performance; problems with electron states produced at the interface between gallium arsenide and most insulators make integrated circuit manufacture with this material considerably more difficult and expensive than with silicon. High-quality single-crystal wafers of gallium arsenide are also more costly to produce.

Photovoltaic cells. Gallium arsenide solar cells have been developed with efficiencies exceeding 20%, which is substantially higher than those obtained with any other material investigated so far. These cells also possess superior high temperature characteristics and their performance is relatively unaffected by exposure to cosmic radiation. The principal factor limiting the widespread use of gallium arsenide in solar cells has been mainly the high cost of manufacture of the single-crystal wafers required for these devices compared with those of silicon.

Lasers. Solid state heterojunction lasers of gallium arsenide and gallium aluminium arsenide are used in conjunction with optical fibers in telecommunications. Experimental communications systems based on optical fiber technology are already in operation in a number of countries, including the UK. A large expansion of this field is envisaged throughout the 1980s. However, a move to low transmission frequencies would result in a switch from gallium arsenide to indium phosphide in lasers.

Figure 26.

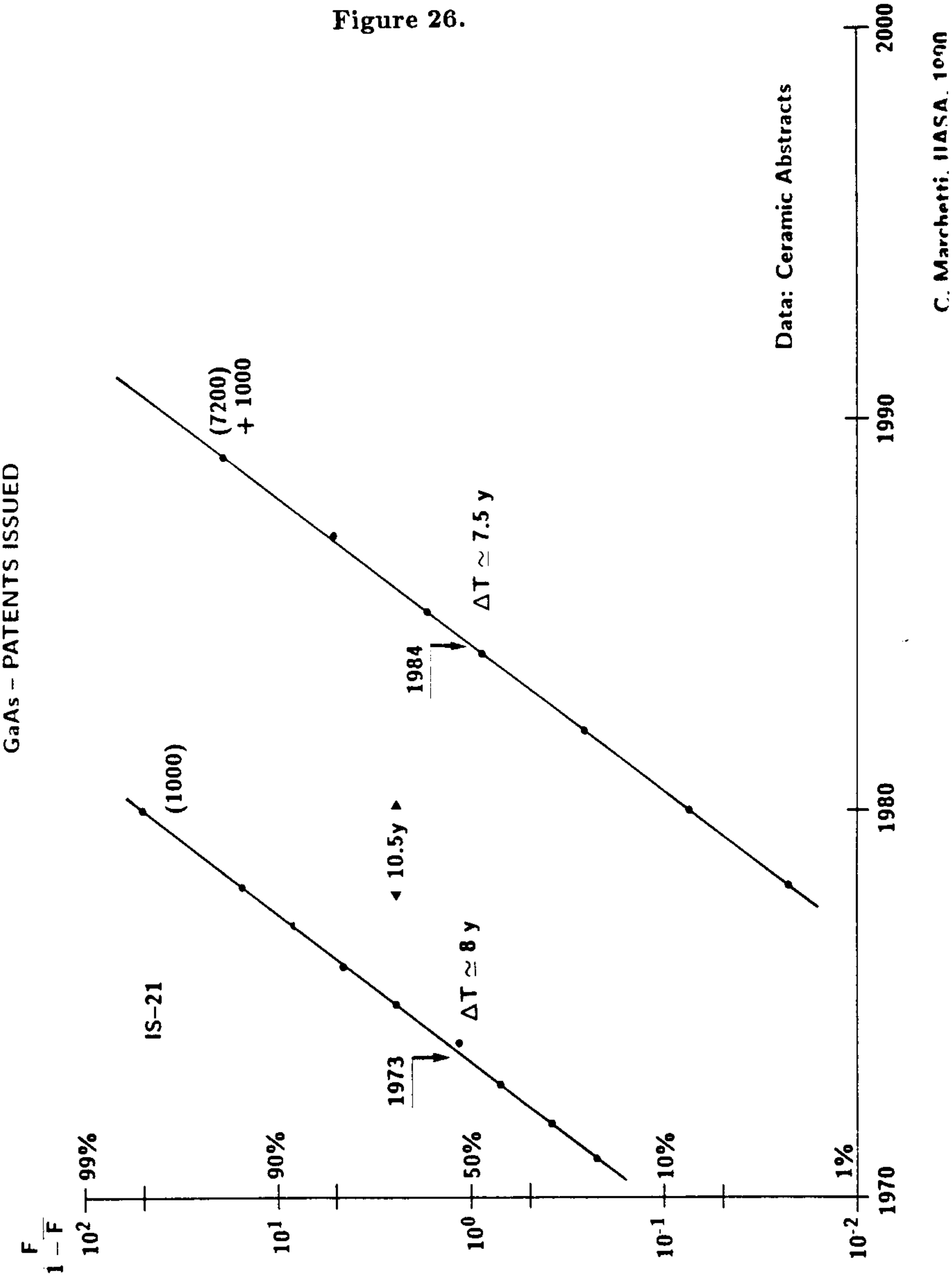

GaAs – PATENTS ISSUED
IS–21
Data: Ceramic Abstracts
C. Marchetti, IIASA, 1990
(1000)
(7200)
+ 1000
◂ 10.5y ▸
ΔT ≃ 8 y
ΔT ≃ 7.5 y
1973
1984
F / 1 – F
10^2
10^1
10^0
10^-1
10^-2
99%
90%
50%
10%
1%
1970
1980
1990
2000

Figure 26.

The analysis of patents (Fig.26) referring to GaAs as from *Ceramic Abstracts* shows the great interest in GaAs devices witnessed by the unusually large number of patents (more than 8000 at saturation). The first wave is quite early, centered in 1973 with 1000 patents as saturation point and a time constant of 8 years. The second wave, almost an order of magnitude larger, is centered in 1984 with 7200 patents at saturation and a similar time constant (7.5 years). The relative narrowness of these waves (80% of the patents are inside the time constant period) can be an indicator of bandwagon or cascading effects.

Electrically Conductive Polymers

Solid state physics led the way to make electrons (and ions) mobile into plastic materials, with dreams about superconductivity.

The area is moving fast, especially because tailored molecules may lead to micro-micro switching circuits for very compact computers.

To stay on the easy side, contemplated in the analysis of patents and publications here annexed, sheets of polyacetylene and others appear to have exceptional market potential for use especially in automotive batteries. Their combination of good power flow, ease of fabrication, versatility of physical shape, very low density, make them the only materials which a realistic chance of making competitive battery vehicles.

Inspection of the content of the patents show that the first wave is devoted mainly to polymer films and varnishes to eliminate statics, the second wave, on the contrary, concentrates on battery applications.

Figure 27.

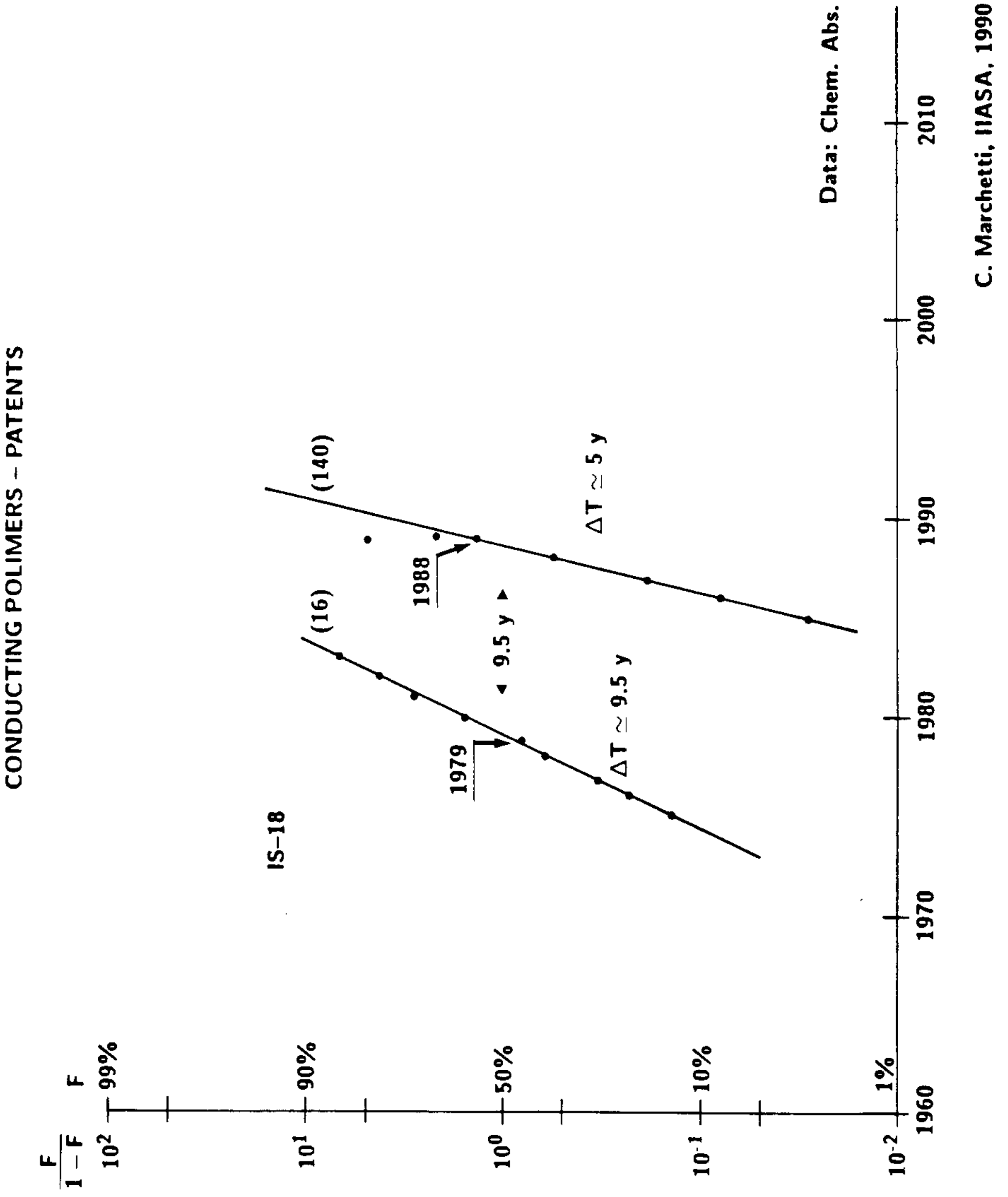
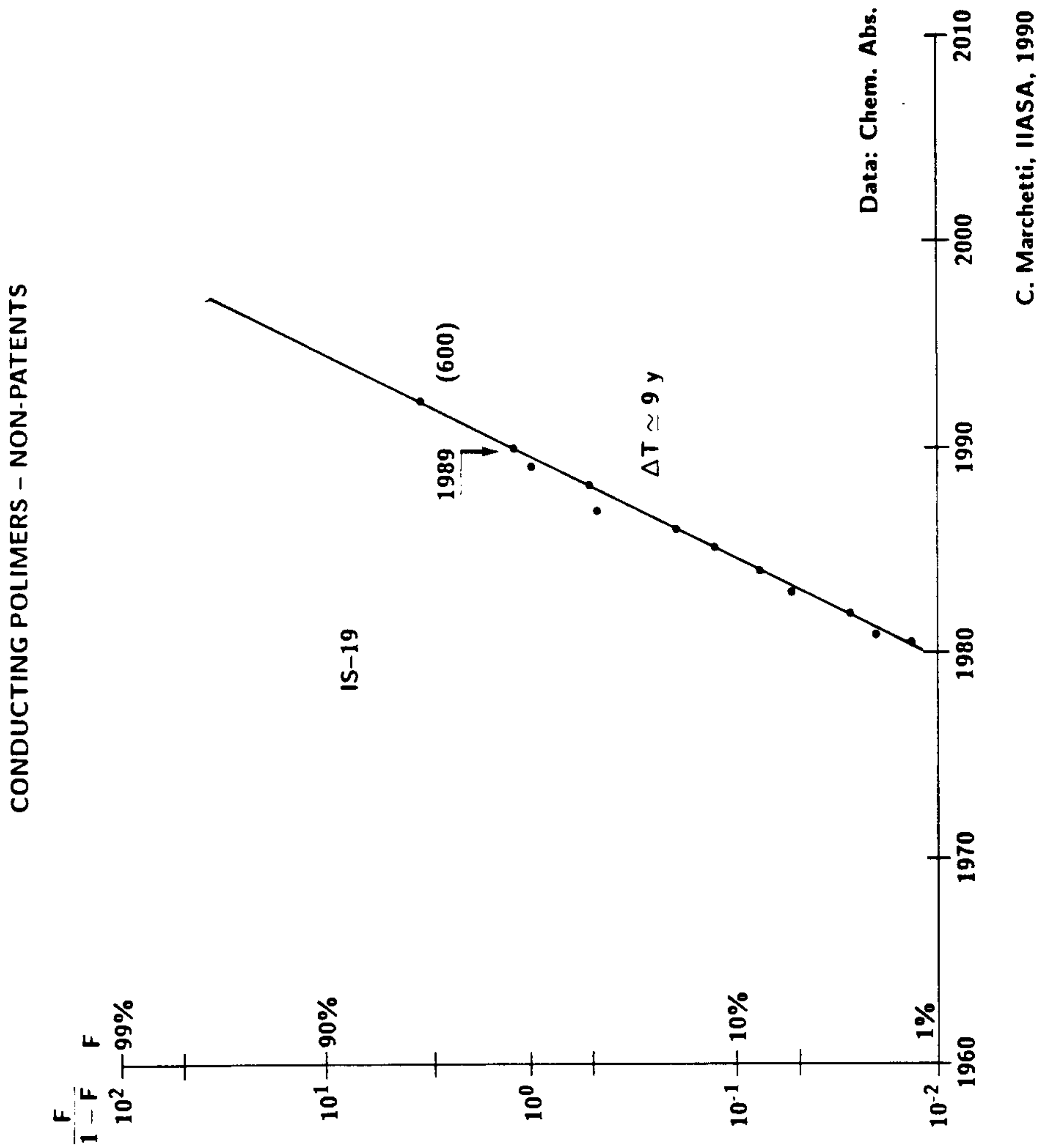

CONDUCTING POLIMERS – PATENTS
IS-18
Data: Chem. Abs.
C. Marchetti, IIASA, 1990
(16)
(140)
1979
1988
9.5 y
ΔT ≃ 9.5 y
ΔT ≃ 5 y
F/(1 – F)
F
99%
90%
50%
10%
1%
1960
1970
1980
1990
2000
2010

Figure 28.


CONDUCTING POLIMERS - NON-PATENTS
IS-19
(600)
1989
ΔT ≃ 9 y
Data: Chem. Abs.
C. Marchetti, IIASA, 1990
F/(1 - F)
F
10^2
10^1
10^0
10^-1
10^-2
99%
90%
10%
1%
1960
1970
1980
1990
2000
2010

Figures 27, 28.

Following our taxonomic exercise, we shall examine the case of *Conducting Polymers* where patents precede publications with a first pulse centered in 1979 with 26 papers and a time constant of 9.5 years. A second pulse is centered in 1988 with 140 objects and a very short time constant of 5 years. Publications have one pulse only with 600 objects, centered in 1989. Due to the large number of publications and a relatively long time constant of 9 years, one might argue that the tail of this bunch of publications may have nurtured the first pulse of patents.

Optical Fibers

Optical fibers are one of the star performers in the development of materials during the last 20 years. This on the side of the physical properties of the material where, e.g., transparency has been increased by orders of magnitude and on the side of fabrication where fibers of uniform size down to a few microns with all sorts of sheetings around them, are currently fabricated in kilometers apiece.

These fibers can conduct light for imaging purposes as in the endoscopes of medicine, or can carry light modulated for information, e.g., for telephonic transmission. The very high transmission capacity, orders of magnitude superior to that of metallic cables, the development of very compact electro-optic interfaces, the resistance to electric interferences, and the basic low volume low cost of the machinery is making applications and proposed applications grow exponentially. Behind that is an *extremely sophisticated work in materials development,* materials processing, and materials manufacturing. An estimate of the work done comes out also from the very large number of publications and patents on the subject.

Figure 29.

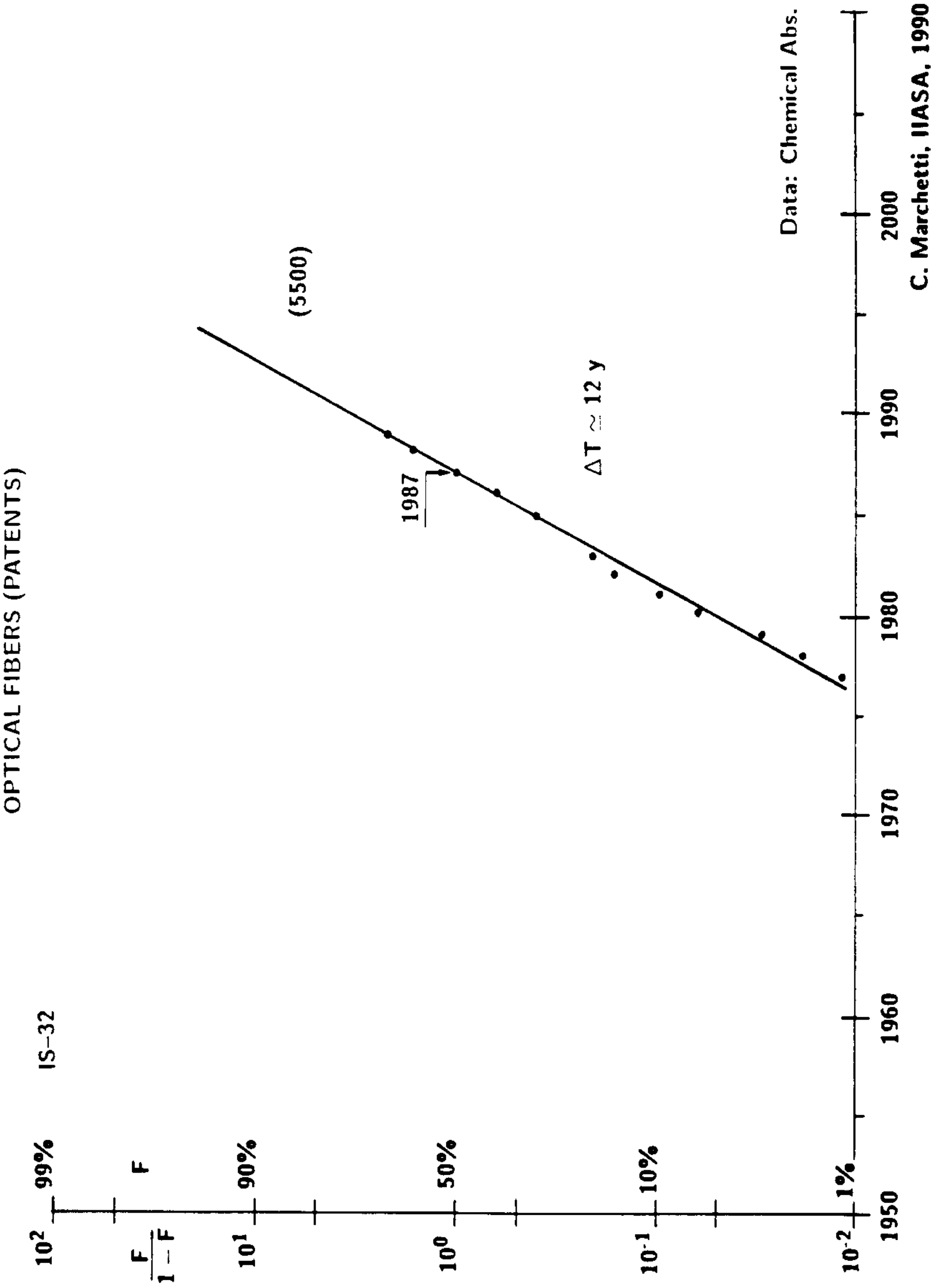
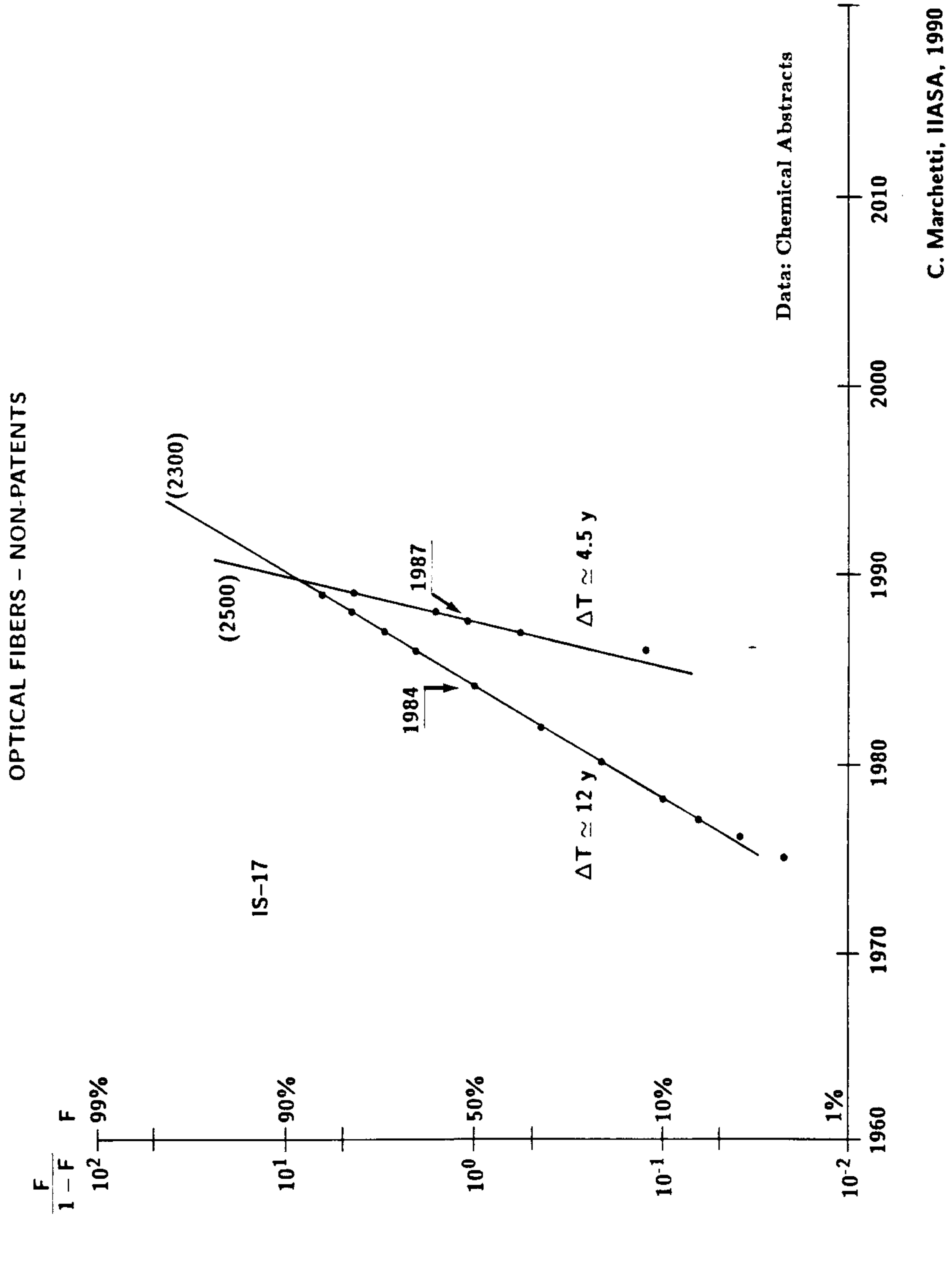

OPTICAL FIBERS (PATENTS)
IS–32
(5500)
ΔT ≃ 12 y
1987
Data: Chemical Abs.
C. Marchetti, IIASA, 1990
F/(1 – F)
F
10²
10¹
10⁰
10⁻¹
10⁻²
99%
90%
50%
10%
1%
1950
1960
1970
1980
1990
2000

Figure 30.


OPTICAL FIBERS – NON-PATENTS
IS–17
$\frac{F}{1-F}$
F
10^2
99%
10^1
90%
10^0
50%
10^{-1}
10%
10^{-2}
1%
1960
1970
1980
1990
2000
2010
(2300)
(2500)
1987
1984
ΔT ≃ 4.5 y
ΔT ≃ 12 y
Data: Chemical Abstracts
C. Marchetti, IIASA, 1990

Figures 29, 30.

The publications on optical fibers have been taken from *chemical Abstracts*. The sum of the saturating levels of the two pulses amount to about 5000. The first pulse is a slow one with an unusually long time constant of 12 years, centered in 1984 (2300 items at saturation). The second is a fast one with a time constant of 4.5 years, centered in 1987 (2500 items at saturation). the time to join the bandwagon seems gone, unless some brand new idea may restart the show. Patents come in a go of 5500 items at saturation, and are still on the way. The time constant is again quite long, 12 years, remembering that of publications. The distance between centerpoints is only three years which may suggest some causal links. To be verified by close analysis of a sample of publications and patents, respectively.

Figure 31.

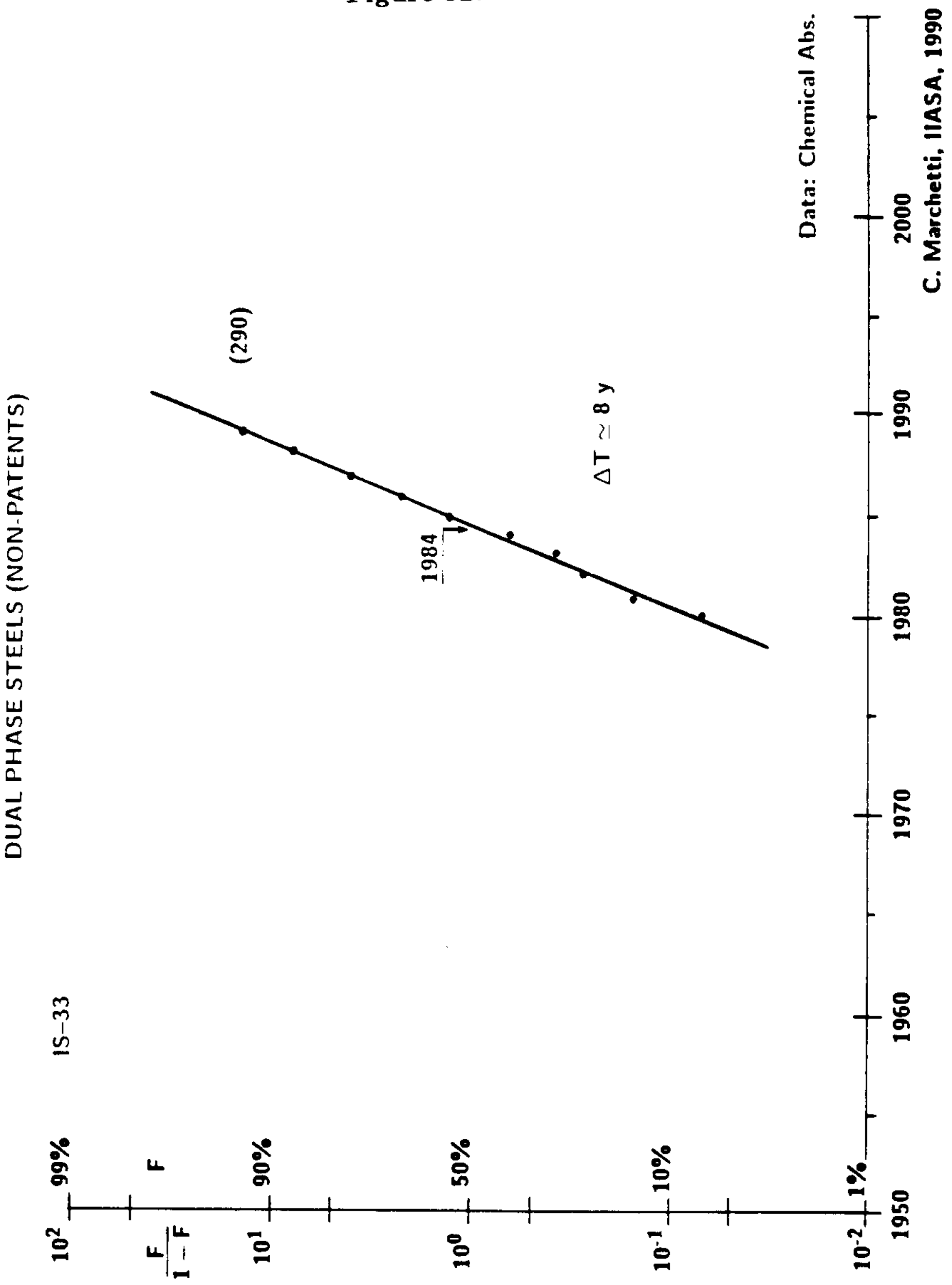
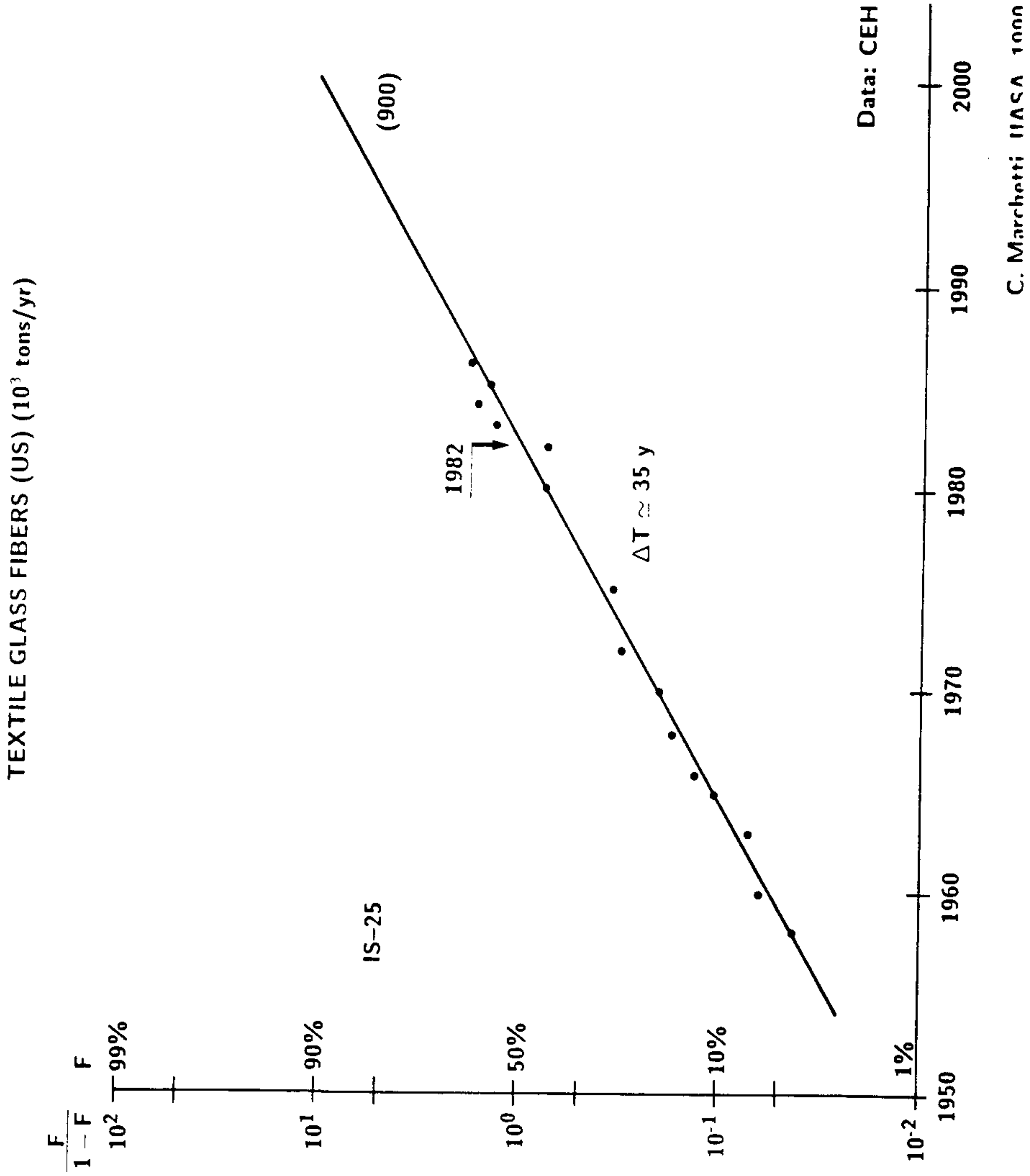

DUAL PHASE STEELS (NON-PATENTS)
IS–33
(290)
ΔT ≃ 8 y
1984
Data: Chemical Abs.
C. Marchetti, IIASA, 1990
F/(1 – F)
F
10^2 99%
10^1 90%
10^0 50%
10^-1 10%
10^-2 1%
1950
1960
1970
1980
1990
2000

Figure 31.

Dual Phase Steels

We are just glancing at the publications in a backwater area far from the limelights of the press and the dominant journals. The period covered by the data is 1980–1989 and this may miss publication waves before 1975. That said, the deployment of publications follows the same rules as for the bandwagon subjects, including the short time constant of 8 years. The centerpoint is 1984.

Figure 32.



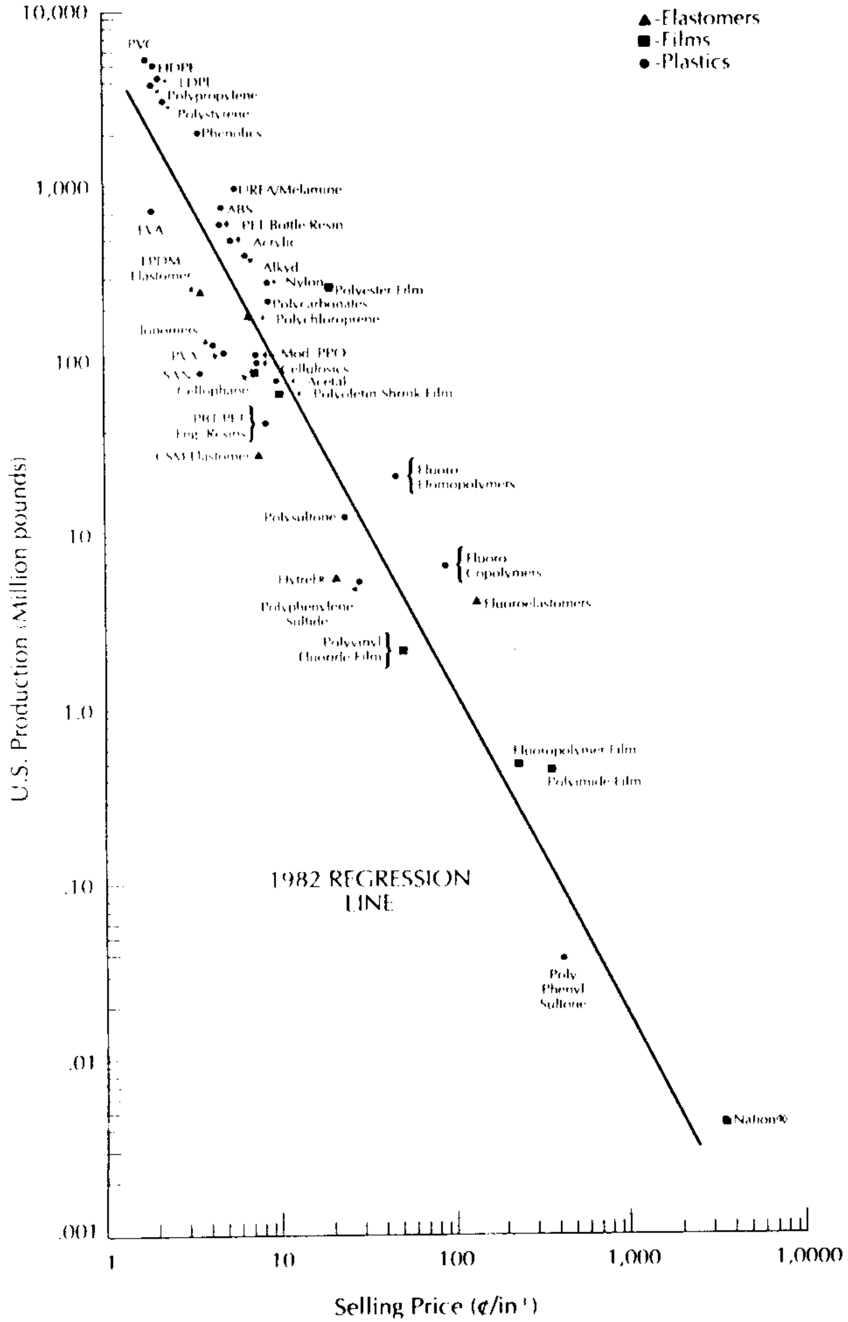
TEXTILE GLASS FIBERS (US) (10³ tons/yr)
Data: CEH
C. Marchetti
(900)
1982
ΔT ≃ 35 y
IS–25
F/(1 − F)
F
10²
10¹
10⁰
10⁻¹
10⁻²
99%
90%
50%
10%
1%
1950
1960
1970
1980
1990
2000

Figure 32.

Textile Glass Fibers

TGF are one of the most popular fillers of plastic structures, giving the strength necessary for mechanical performance. Boats, roofs, boxes and containers of all sizes and shapes are built using TGF and a plastic filler. So it is not a newcomer and in fact commerce in TGF has flourished now for almost 50 years. The reason to put it in our collection is that reasonable statistics exist for the USA on the consumption of this materials.

The analysis has been done fitting a penetration logistic to annual production. the centerpoint is relatively late (1982) and the time constant large (35 years) showing it one of the rare products that do not saturate with the end of the Kondraticv cycle.



Polimeric materials and their niches.

As the chart, drawn for polimers, but typical for any class of materials, shows, price is no barrier to the introduction of novel things with novel properties. Extremely expensive magnetic materials can find a profitable niche in electric watches.

Normally the highest prices command the smallest niche, although there is much spread in that log-log chart probably due to the very different age of the various niches.

Plastic Materials

Finding reliable data on production capacity and sales of really advanced materials is difficult, bu for well established materials like, for example, PVC, the situation is a little better. Data on plastic materials in pipes for the USA, have been collected by Ginley of the Bureau of Mines. In particular for PVC, which is one of the winning horses in substituting metals, especially for underground water and sewage pipes.

We have done two analyses, reported in Fig.33 and Fig.34, to show that the diffusion model catches well the process of market penetration and substitution of materials that were brand new and somehow advanced 40 years ago when they were introduced into the big market. The analysis of market share in terms of fraction in volumes of pipe material shows an interesting feature: it saturates around 70% indicating the existence of market niche inaccessible to present day plastic materials.

We are now at the end of a Kondratiev cycle with all the innovation rush usually associated with it. We may then expect new plastics emerging in this wave of innovations being able to penetrate even these niches. If I had to drop names I would say oil and gas transport could benefit from high mechanical and chemical resistance, e.g., of Liquid Crystal Polymers. The possibility of a machine that extrudes the pipe along the way in a single piece is a gleam in the eye of pipelayers. Intrinsically fibrous plastics and Liquid Crystal Polymers may compete with good steels, if not yet economically, and might permit higher operations pressures in the pipelines. They can exhibit tensile strength up to 15 times that of steel, are resistant to chemicals and have negligible creep.

Figure 33.

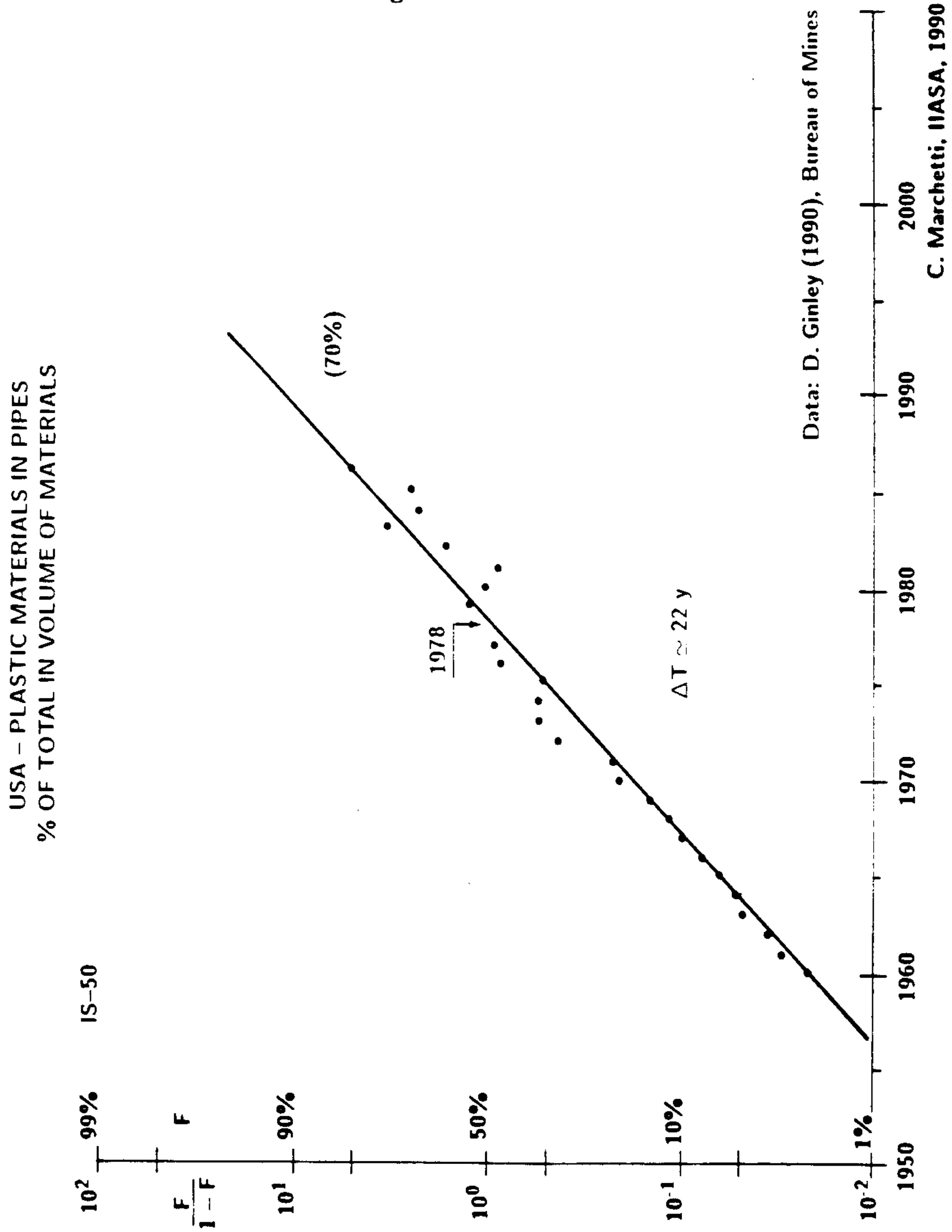
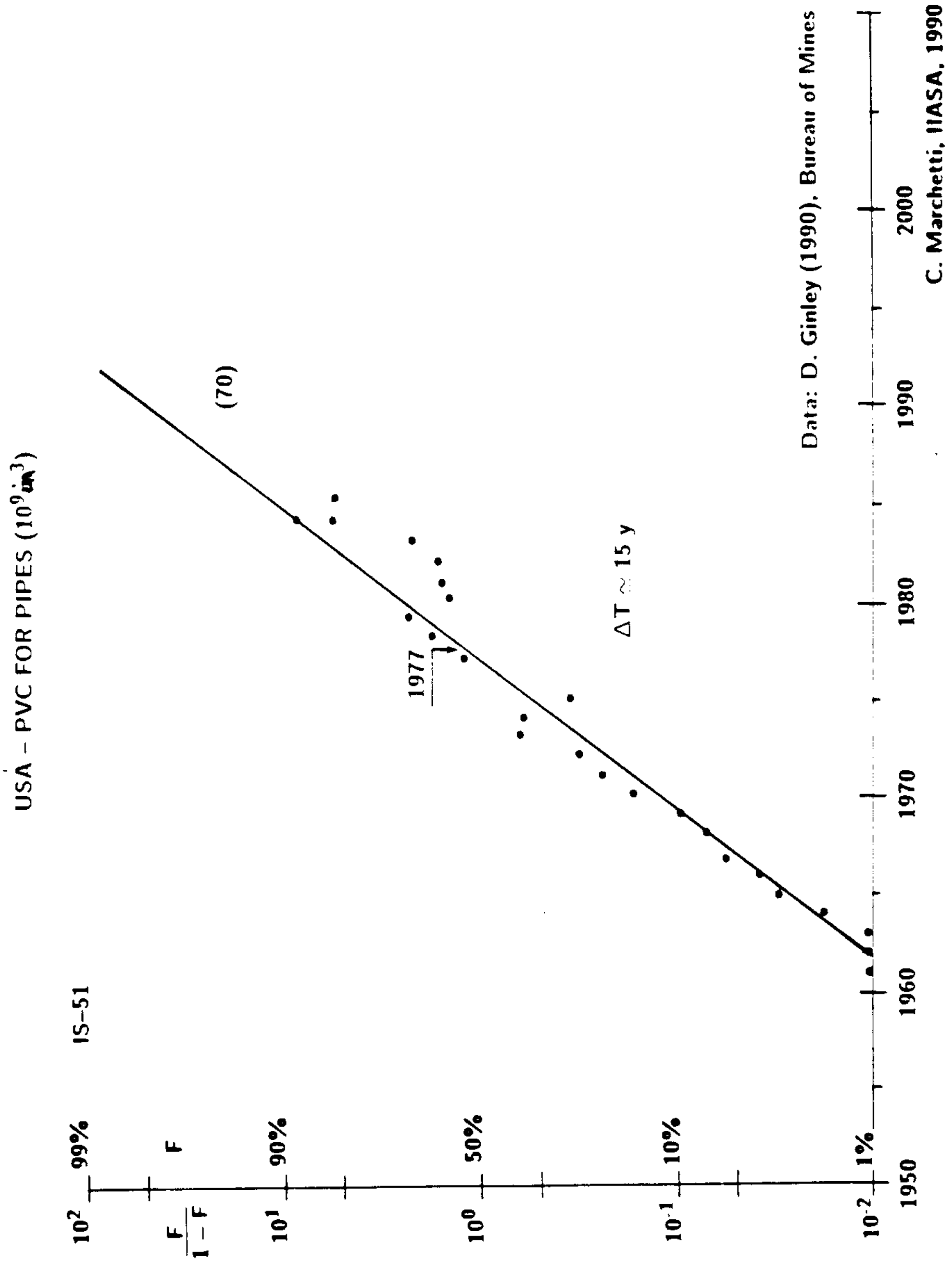

USA – PLASTIC MATERIALS IN PIPES
% OF TOTAL IN VOLUME OF MATERIALS
IS–50
(70%)
1978
ΔT ≃ 22 y
Data: D. Ginley (1990), Bureau of Mines
C. Marchetti, IIASA, 1990
99%
F
90%
50%
10%
1%
10^2
$\frac{F}{1-F}$
10^1
10^0
10^{-1}
10^{-2}
1950
1960
1970
1980
1990
2000

Figure 34.



USA - PVC FOR PIPES $(10^9 m^3)$
IS-51
(70)
1977
$\Delta T \simeq 15$ y
Data: D. Ginley (1990), Bureau of Mines
C. Marchetti, IIASA, 1990
10^2
10^1
10^0
10^{-1}
10^{-2}
$\frac{F}{1-F}$
F
99%
90%
50%
10%
1%
1950
1960
1970
1980
1990
2000

Figures 33, 34.

These last two charts report the analysis of the market penetration of plastics in a particular niche, that of piping. The analysis is done first (Fig.33) in a *global substitution* form looking at the percentage of pipes (volume) constructed using plastics of all kind. The substitution process can be well described by a logistic equation even if after 1972 the system becomes somehow noisy. It is interesting that the saturation level is at 70% of the total volume of piping, showing some part of this niche being inaccessible to plastics. The second analysis (Fig.34) is done looking at the absolute amount ($10^9 in^3$) of a given plastic (PVC) employed for the construction of pipes. Also here the trend is well organized around the logistic with an expected saturation of 70 $10^9 in^3$: In both examples saturation is approaching, presumably in connection with the end of the present Kondratiev cycle (1995).

Literature

Literature on materials and new materials is luxuriant, but mostly descriptive of past events or wishful about the future. A theoretical framework of the kind I have started to put together here the bits and pieces, is completely lacking. In the following I have listed a few papers and books that transited my desk during this study which were marked for some merit.

Jerry Hausman, Bronwyn H. Hall, Zvi Griliches, 1984, Econometric Models for Count Data with an Application to the Patents–R&D Relationship, *Econometrica* **52**(4):909–938.

Bureau of Mines, 1990, The New Materials Society, Volumes 1 and 2, US Department of the Interior.

D. Altenpohl, 1980, Materials in World Perspective, Springer-Verlag.

New Advanced Materials, FAST Report, Springer-Verlag.

Tom Forester, ed., 1988, The Materials Revolution, The MIT Press.

New Structural Materials Technologies, Office of Technological Assessment, September 1986, Washington.

Materials Science and Engineering for the 1990s, National Academy of Sciences, National Academy Press, Washington, 1989.

Hill Michall, 1989, Information from Patents – An Overview of Recent Activities, *Online Review* **13**(3):199.

Narin Francis, E. Noma, R. Perry, 1987, Patents as Indicators of Corporate Technological Strength, *Research Policy* **16**:143–155.

Achilledelis Basil, A. Schwarzkopf, M. Cines, 1990, The Dynamics of Technological Innovation: The Case of the Chemical Industry, *Research Policy* **19**:1–34.

Bronwyn H. Hall, Zvi Griliches, Jerry A. Hausman, 1986, Patents and R&D: Is There a Lag? *International Economic Review* **27**(2):265.

Marvin B. Lieberman, 1978, A Literature Citation Study of Science–Technology Coupling in Electronics, *Proceedings of the IEEE* **66**(1):5.

Diana Hicks, Ben R. Martin, John Irvine, 1986, Bibliometric Techniques for Monitoring Performance in Technological Oriented Research: The Case of Integrated Optics, *R&D Management* **16**(3):211.

Francis Narin, Mark Carpenter, Are Technology and Science Becoming Indistinguishable?

K. Pavitt, 1985, Patent Statistics as Indicators of Innovative Activities: Possibilities and Problems, *Scientometrics* **7**(1–2):77–99.

Mark Schankerman, Ariel Pokes, 1983, The Rate of Obsolescence and the Distribution of Patent Values. Some Evidence from European Data, Conference on Quantitative Studies of R&D in Industry, Paris.

Frant de Hond, Peter Groeneweyer, Philip Vergragt, 1990, Technology Assessment, Expectations and Networks: An Illustration Using New Materials, *Project Appraisal* **5**(2):83–92.

Zoltan J. Acs, David B. Andretsch, 1989, Patents as a Measure of Innovative Activity, *Kyklos* **42**(2):171–180.

F. Liebesny, J.W. Hewitt, P.S. Hunter, M. Hannah, 1974, The Scientific and Technical Information Contained in Patent Specifications – The Extent and Time Factors of its Publication in Other Forms of Literature, *The Information Scientist*:165.

Commission of the European Communities, 1987, Les Materiaux Nouveaux – Dynamique Economique et Stratégie Européenne, FAST Programme, FOP No. 146, Brussels.

Forest, Tim, 1988, New Materials, *Science and Public Policy* **15**(4).

US Industrial Outlook 1990 – Advanced Materials

Report on Artificially Structured Materials, National Academy Press, Washington, 1985.

Advanced Processing of Electronic Materials in the US and Japan, National Academy Press, Washington, 1986.

N. Nakicenovic, 1985, *Patterns of change – Technological Substitution and Long Waves in the United States*, WP-85-50, International Institute for Applied Systems Analysis, Laxenburg, Austria.

A.L. Lotka, 1956, *Elements of Mathematical Biology*, Dover Publications, New York.

P.F. Verhulst, 1845, *Nonv. Mem. Acad. R. Soc. et Belles-Lett.*, Brussels.

J.B.S. Haldane, 1924, The Mathematical Theory of Natural and Artificial Selection, *Trans. Cambridge Philos. Soc.* **23**:19.

A. Debecker and T. Modis, 1986, *Determination of the Uncertainties in S-Curve Logistic Fits*, Digital Equipment Corporation, Geneva.

MATHEMATICAL APPENDIX

The equations for dealing with different cases are reducible to the general Volterra–Lotka equations

$$\frac{dN_i}{dt} = K_i N_i + \beta_i^{-1} \sum_{n}^{j=1} a_{ij} N_i N_j \quad , \tag{1}$$

where N_i is the number of individuals in species i, and a, β, and K are constants. The equation says a species grows (or decays) exponentially, but interacts with other species. A general treatment of these equations can be found in Montroll and Goel (1971) and Peschel and Mende (1986). Since closed solutions exist only for the case of one or two competitors, these treatments mainly deal with the general properties of the solutions.

To keep the analysis at a physically intuitive level, I use the original treatment of Verhulst (1845) for the population in a *niche* (Malthusian) and that of Haldane (1924) for the competition between two genes of different fit. For the multiple competition, a computer package has been developed that works perfectly for actual cases (Marchetti and Nakicenovic, 1979), but whose identity with the Volterra equations is not fully proved (Nakicenovic, 1979). Most of the results are presented using the coordinates for the linear transform of a logistic equation originally introduced by Fisher and Pry (1970).

The Malthusian Case

This modeling of the dynamics of population systems started with Verhulst in 1845, who quantified the Malthusian case. A physically very intuitive example is given by a population of bacteria growing in a bottle of broth. Bacteria can be thought of as machinery that transforms a set of chemicals in the broth into bacteria. The rate of this transformation, *coeteris paribus* (e.g., temperature), can be seen as proportional to the number of bacteria (the transforming machinery) and the concentration of the transformable chemicals.

Since all transformable chemicals will be converted eventually into bacterial bodies, one can measure broth chemicals in terms of bacterial bodies using homogeneous units. So $N(t)$ is the number of bacteria at time t, and $\bar{N}$ is the amount of transformable chemicals at time 0, before multiplication starts. The Verhulst equation can then be written

$$\frac{dN}{dt} = aN(\bar{N} - N) \quad , \tag{2}$$

whose solution is

$$N(t) = \frac{\bar{N}}{1-e^{-(at+b)}} \quad , \tag{3}$$

with b an integration constant, sometimes written as t_0, i.e., time at time 0; a is a rate constant that is assumed to be independent of the size of the population. This means that there is no "proximity feedback". If we normalize to the final size of the system, $\bar{N}$, and explicate the linear expression, equation (2) can be written in the form suggested by Fisher and Pry (1970)

$$\log\frac{F}{1-F} = at + b \quad , \quad \text{where } F = \frac{N}{\bar{N}} \quad . \tag{4}$$

Most of the charts are presented in this form. The variable $\bar{N}$ is often called the *niche*, and the growth of a population is given as the fraction of the niche it fills.

The fitting of empirical data requires calculation of the three parameters $\bar{N}$, a, and b, for which there are various recipes (Oliver, 1964; Blackman, 1972; Bossert, 1977). The problem is to choose the physically more significant representation and procedure. I personally prefer to work with the Fisher and Pry transform, because it operates on ratios (e.g., of the size of two populations), and ratios seem to me more important than absolute values, both in biology and in social systems.

The calculation of $\bar{N}$ is usually of great interest, especially in economics. However, the value of $\bar{N}$ is very sensitive to the value of the data, i.e., to their errors, especially at the beginning of the growth. The problem of assessing the error on $\bar{N}$ has been studied by Debecker and Modis (1986), using numerical simulation.

The Malthusian logistic must be used with great precaution because it contains implicitly some important hypothesis:

- that there are no competitors in sight
- that the size of a niche remains constant
- that the species and its boundary conditions (e.g., temperature for the bacteria) stay the same.

The fact that in multiple competition the starts are always logistic may lead to the presumption that the system is Malthusian. When the transition period starts there is no way of patching up the logistic fit.

The fact that the niches keep changing, due to the introduction of new technologies, makes this treatment, generally speaking, unsuitable for dealing with the growth of human populations, a subject in which Pearl (1924) first applied logistics. Since the treatment sometimes works and sometimes does not work, one can find much faith and disillusionment among demographers.