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# THERMAL CONDUCTIVITY OF FREON-218


V. P. Baryshev, S. D. Artamonov, and V. Z. Geller



UDC 536.22



The thermal conductivity of Freon-218 is investigated experimentally in a wide region of the parameters. Reference tables of thermal conductivity are compiled.


Freon-218 ($C_3F_8$) is a promising agent for refrigeration and especially for cryogenic engineering, but its application is limited by the absence of data on the thermophysical properties in the region of the parameters required in practice. Earlier we [1] determined the thermal conductivity of Freon-218 at low temperatures (from 113 to 297°K). The aim of the present report is an investigation of the thermal conductivity of Freon-218 at moderate and moderately high temperatures (up to 430°K) and pressures up to 60 MPa, as well as the development of reference tables of λ.

The thermal conductivity was measured by the hot-filament method using a cell whose construction is described in [2]. In all the tests λ was determined at different temperature drops in the layer, with the Rayleigh numbers not exceeding 1500. The region of the maxima (at $0.6 < \omega < 1.4$ and $\tau < 1.15$) was not investigated. The experimental results are presented in Table 1.

In the treatment of the measurement results we analyzed the equations

$$\lambda - \lambda_t = \sum_{i=1}^{n} \sum_{j=0}^{s_i} a_{ij} \omega^i / \tau^j, \tag{1}$$

$$\ln(\lambda/\lambda_t) = \sum_{i=1}^{n} \sum_{j=0}^{s_i} a_{ij} \omega^i / \tau^j. \tag{2}$$


M. V. Lomonosov Odessa Technological Institute for the Food Industry. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 38, No. 2, pp. 244-248, February, 1980. Original article submitted May 3, 1979.




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TABLE 1. Experimental Values of Thermal Conductivity of Freon-218, $10^4$ W/(m•°K)

| $T$, °K | $\lambda$ |
|---|---|
| $P = 0{,}10$ MPa | |
| 287,0 | 127,2 |
| 314,0 | 145,9 |
| 314,9 | 146,1 |
| 335,0 | 159,9 |
| 335,2 | 160,9 |
| 355,2 | 174,5 |
| 364,7 | 181,0 |
| 365,6 | 181,4 |
| 389,5 | 199,5 |
| 403,1 | 209 |
| 403,8 | 209 |
| 433,5 | 232 |
| 434,2 | 231 |
| $P = 0{,}24$ MPa | |
| 262,8 | 116,1 |
| 263,9 | 114,9 |
| 266,5 | 155,6 |
| $P = 0{,}42$ MPa | |
| 262,1 | 577 |
| 262,6 | 573 |
| $P = 0{,}58$ MPa | |
| 286,9 | 131,5 |
| 287,7 | 132,5 |
| $P = 0{,}72$ MPa | |
| 286,4 | 504 |
| 286,8 | 504 |
| $P = 1{,}08$ MPa | |
| 433,7 | 238 |
| 434,7 | 238 |
| 338,6 | 172,1 |
| 339,3 | 172,6 |
| 334,9 | 170,0 |
| 335,7 | 170,4 |
| 374,1 | 197,2 |
| 374,8 | 197,1 |
| $P = 1{,}12$ MPa | |
| 262,2 | 577 |
| 262,8 | 577 |
| $P = 1{,}37$ MPa | |
| 313,9 | 439 |
| 314,2 | 439 |
| $P = 1{,}84$ MPa | |
| 324,8 | 407 |
| 325,0 | 413 |
| 333,7 | 195,8 |
| 334,0 | 199,1 |
| $P = 1{,}90$ MPa | |
| 329,7 | 399 |
| 329,9 | 409 |
| 329,6 | 391 |
| $P = 2{,}05$ MPa | |
| 333,6 | 199,5 |
| 334,2 | 205 |
| 335,9 | 193,2 |
| 336,1 | 198,3 |
| 336,4 | 204 |
| 338,2 | 207 |
| 338,8 | 214 |
| 338,4 | 208 |
| 332,9 | 378 |
| 333,0 | 387 |
| 333,1 | 404 |
| $P = 2{,}11$ MPa | |
| 353,6 | 203 |
| 354,2 | 205 |
| 363,8 | 207 |
| 364,4 | 207 |
| $P = 3{,}08$ MPa | |
| 433,4 | 256 |
| 434,0 | 256 |
| 324,8 | 432 |
| $P = 3{,}08$ MPa | |
| 325,0 | 429 |
| 313,9 | 455 |
| 314,2 | 460 |
| 353,3 | 459 |
| 353,4 | 520 |
| 363,2 | 255 |
| 363,4 | 259 |
| 373,7 | 236 |
| 374,0 | 239 |
| 262,5 | 591 |
| 263,2 | 590 |
| 388,0 | 239 |
| 388,4 | 230 |
| 402,9 | 239 |
| 403,2 | 421 |
| $P = 4{,}02$ MPa | |
| 433,5 | 272 |
| 433,9 | 271 |
| 338,1 | 413 |
| 338,3 | 410 |
| 338,6 | 416 |
| $P = 5{,}00$ MPa | |
| 338,3 | 303 |
| $P = 5{,}00$ MPa | |
| 388,4 | 313 |
| 388,6 | 325 |
| 286,6 | 536 |
| 287,1 | 536 |
| 313,9 | 477 |
| 314,2 | 478 |
| 329,7 | 431 |
| 329,9 | 433 |
| 332,9 | 425 |
| 333,1 | 427 |
| 353,3 | 388 |
| 353,5 | 394 |
| 353,9 | 407 |
| 358,5 | 383 |
| 358,8 | 398 |
| 359,3 | 418 |
| 363,3 | 345 |
| 363,4 | 379 |
| 363,4 | 379 |
| 373,7 | 359 |
| 373,9 | 371 |
| 374,2 | 396 |
| 433,3 | 290 |
| 433,8 | 290 |
| $P = 5{,}06$ MPa | |
| 262,2 | 600 |
| 262,6 | 601 |
| 324,8 | 448 |
| 325,0 | 449 |
| 402,9 | 295 |
| 403,0 | 302 |
| 403,4 | 307 |
| $P = 9{,}91$ MPa | |
| 325,2 | 497 |
| 329,7 | 486 |
| 329,9 | 486 |
| 353,3 | 455 |
| 353,5 | 452 |
| 363,6 | 434 |
| 363,9 | 437 |
| 373,9 | 426 |
| 374,4 | 429 |
| 433,2 | 373 |
| 433,6 | 378 |
| 434,2 | 386 |
| $P = 19{,}71$ MPa | |
| 261,4 | 678 |
| 262,1 | 679 |
| 286,4 | 625 |
| 286,9 | 625 |
| 314,0 | 576 |
| $P = 19{,}71$ MPa | |
| 314,3 | 576 |
| 333,5 | 546 |
| 333,9 | 549 |
| 338,2 | 544 |
| 338,5 | 545 |
| 353,4 | 536 |
| 353,6 | 532 |
| 363,7 | 518 |
| 364,1 | 514 |
| 374,0 | 510 |
| 374,4 | 501 |
| 402,8 | 484 |
| 403,1 | 484 |
| 433,3 | 477 |
| 433,6 | 469 |
| $P = 39{,}32$ MPa | |
| 262,2 | 795 |
| 262,7 | 757 |
| 313,9 | 673 |
| 314,1 | 672 |
| 333,5 | 648 |
| 333,9 | 647 |
| 338,4 | 648 |
| 338,7 | 639 |
| 353,4 | 625 |
| 353,4 | 624 |
| 353,6 | 628 |
| 363,8 | 625 |
| 364,2 | 619 |
| 374,0 | 616 |
| 374,5 | 608 |
| 403,0 | 608 |
| 403,2 | 604 |
| 403,4 | 589 |
| 433,1 | 600 |
| 433,4 | 583 |
| $P = 58{,}94$ MPa | |
| 262,2 | 822 |
| 262,8 | 824 |
| 314,0 | 752 |
| 314,5 | 748 |
| 333,6 | 728 |
| 334,0 | 721 |
| 338,3 | 723 |
| 338,6 | 715 |
| 353,5 | 715 |
| 354,0 | 703 |
| 363,8 | 704 |
| 364,3 | 697 |
| 374,1 | 695 |
| 374,6 | 690 |

The temperature dependence of $\lambda_t$ was approximated in the form

$$\lambda_t = \sum_{i=0}^{2} a_i \tau^i, \qquad (3)$$

where $a_0 = -0.7684 \cdot 10^2$, $a_1 = 0.7097 \cdot 10^0$, and $a_2 = 0.2387 \cdot 10^{-5}$.

The p, ρ, and T data on Freon-218 required for the treatment were obtained by us [3] by the method of a constant-volume piezometer and hydrostatic weighing in the temperature range of 133-430°K and the pressure range of 0.1-50 MPa. The following values of the critical parameters were adopted in accordance with [4]: $T_{cr} = 345.1 \pm 0.2$°K; $p_{cr} = 2.68 \pm 0.01$ MPa; $\rho_{cr} = 628 \pm 1$ kg/m³.

TABLE 2. Errors in Describing the Array of Initial Data by Equations of the Type of (1)

| $m$ | $S_1$ | $S_2$ | $S_3$ | $S_4$ | $S_5$ | σ, % | $m$ | $S_1$ | $S_2$ | $S_3$ | $S_4$ | σ, % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4 | 1 | 1 | 1 | 1 | 0 | 2,94 | 4 | 1 | 1 | 1 | 1 | 2,94 |
| 5 | 1 | 1 | 1 | 1 | 1 | 3,09 | 5 | 2 | 1 | 1 | 1 | 1,96 |
| 6 | 2 | 1 | 1 | 1 | 1 | 2,05 | 6 | 2 | 2 | 1 | 1 | 1,91 |
| 7 | 2 | 2 | 1 | 1 | 1 | 1,97 | 7 | 2 | 2 | 2 | 1 | 1,91 |
| 8 | 2 | 2 | 2 | 1 | 1 | 1,99 | 8 | 2 | 2 | 2 | 2 | 2,00 |
| 9 | 2 | 2 | 2 | 2 | 1 | 1,99 | 9 | 3 | 2 | 2 | 2 | 2,30 |
| 10 | 2 | 2 | 2 | 2 | 2 | 2,00 | 10 | 3 | 3 | 2 | 2 | 2,08 |
| 11 | 3 | 2 | 2 | 2 | 2 | 3,60 | 11 | 3 | 3 | 3 | 2 | 1,81 |
| 12 | 3 | 3 | 2 | 2 | 2 | 2,04 | 12 | 3 | 3 | 3 | 3 | 1,83 |
| 13 | 3 | 3 | 3 | 2 | 2 | 2,79 | 13 | 4 | 3 | 3 | 3 | 3,62 |
| 14 | 3 | 3 | 3 | 3 | 2 | 1,57 | 14 | 4 | 4 | 3 | 3 | 2,83 |
| 15 | 3 | 3 | 3 | 3 | 3 | 1,67 | 18 | 5 | 5 | 4 | 4 | 2,01 |
| 18 | 4 | 4 | 4 | 3 | 3 | 1,71 | 19 | 5 | 5 | 5 | 4 | 1,81 |
| 19 | 4 | 4 | 4 | 4 | 3 | 1,75 | 20 | 5 | 5 | 5 | 5 | 3,22 |

TABLE 3. Coefficients of Equation (1)

| $i$ | $j$ | | |
|---|---|---|---|
| | 0 | 1 | 2 |
| 1 | $0,1904922 \cdot 10^3$ | $-0,3176758 \cdot 10^3$ | $0,1535949 \cdot 10^3$ |
| 2 | $0,9613248 \cdot 10^2$ | $0,1537587 \cdot 10^3$ | $0,4940584 \cdot 10^2$ |
| 3 | $-0,1320482 \cdot 10^3$ | $-0,1203320 \cdot 10^3$ | $-0,4416641 \cdot 10^1$ |
| 4 | $0,8577525 \cdot 10^2$ | $-0,3497985 \cdot 10^1$ | $-0,6333333 \cdot 10^1$ |
| 5 | $-0,1102703 \cdot 10^2$ | $0,7977065 \cdot 10^1$ | — |

TABLE 4. Thermal Conductivity of Freon-218 along the Saturation Line, $10^4$ W/(m•°K)

| $T$, °K | λ′ | λ″ | $T$, °K | λ′ | λ″ |
|---|---|---|---|---|---|
| 130 | 1016 | 14,74 | 240 | 642 | 93,2 |
| 140 | 988 | 21,8 | 250 | 613 | 101,1 |
| 150 | 954 | 28,9 | 260 | 584 | 109,3 |
| 160 | 918 | 36,0 | 270 | 556 | 117,3 |
| 170 | 881 | 43,2 | 280 | 529 | 125,9 |
| 180 | 844 | 50,3 | 290 | 502 | 135,3 |
| 190 | 808 | 57,4 | 300 | 477 | 145,9 |
| 200 | 772 | 64,5 | 310 | 452 | 158,6 |
| 210 | 738 | 71,6 | 320 | 427 | 174,6 |
| 220 | 705 | 78,7 | 330 | 402 | 196,7 |
| 230 | 673 | 86,0 | 340 | 373 | 231 |

The efficiency of the description of the array of initial data, which was compiled from 251 test points in the temperature range of 113-435°K and the density range of 5-2100 kg/m³, by equations of the type of (1) and (2) was analyzed by "sorting" powers with respect to ω and τ with a maximum number of coefficients of 20. The variant of Eq. (1) with m = 14 proved to be the optimum (from the point of view of the rms deviation and the number of coefficients) (see Table 2). The coefficients of this equation are presented in Table 3.

Equation (1) was used to calculate the thermal conductivity of Freon-218 both along the saturation line and in the one-phase region. The results of the calculation are presented in Tables 4 and 5. The maxima of the thermal conductivity in the above-indicated region were not tabulated. As shown by a comparison of the experimental and calculated data, the error of the recommended values of the thermal conductivity does not exceed 2-3% in the one-phase region and 3-4% near the saturation curve.

## NOTATION

λ, coefficient of thermal conductivity; $\lambda_t$, coefficient of thermal conductivity in the gaseous phase at atmospheric pressure; λ′, λ″, coefficients of thermal conductivity on the

TABLE 5. Thermal Conductivity of Freon-218 in the One-Phase Region, $10^4$ W/(m•°K)

| T, °K | Pressure, MPa | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0,1 | 0,5 | 1 | 2 | 3 | 4 | 5 | 6 | 8 | 10 | 12 |
| 130 | 1016 | 1016 | 1017 | 1018 | 1018 | 1019 | 1020 | 1021 | 1022 | 1024 | 1025 |
| 140 | 988 | 988 | 989 | 990 | 991 | 993 | 994 | 995 | 998 | 1000 | 1003 |
| 150 | 954 | 955 | 956 | 957 | 959 | 961 | 963 | 964 | 968 | 971 | 975 |
| 160 | 918 | 919 | 920 | 922 | 924 | 926 | 928 | 930 | 935 | 939 | 943 |
| 170 | 881 | 882 | 883 | 886 | 888 | 891 | 893 | 896 | 901 | 906 | 910 |
| 180 | 844 | 845 | 847 | 850 | 852 | 855 | 858 | 861 | 867 | 872 | 878 |
| 190 | 808 | 809 | 811 | 814 | 817 | 820 | 824 | 827 | 833 | 839 | 845 |
| 200 | 773 | 774 | 776 | 779 | 783 | 786 | 790 | 793 | 800 | 807 | 814 |
| 210 | 738 | 740 | 742 | 746 | 750 | 754 | 757 | 761 | 769 | 776 | 783 |
| 220 | 705 | 707 | 709 | 714 | 718 | 722 | 726 | 730 | 738 | 746 | 754 |
| 230 | 673 | 675 | 678 | 682 | 687 | 691 | 969 | 700 | 709 | 717 | 726 |
| 240 | 94,3 | 644 | 647 | 652 | 657 | 662 | 667 | 671 | 681 | 690 | 699 |
| 250 | 101 | 614 | 617 | 623 | 628 | 633 | 639 | 644 | 654 | 663 | 673 |
| 260 | 108 | 585 | 588 | 594 | 600 | 606 | 611 | 617 | 628 | 638 | 648 |
| 270 | 115 | 557 | 560 | 567 | 573 | 579 | 585 | 591 | 603 | 614 | 624 |
| 280 | 122 | 126 | 532 | 540 | 547 | 553 | 560 | 566 | 579 | 591 | 602 |
| 290 | 129 | 132 | 505 | 513 | 521 | 528 | 535 | 542 | 556 | 568 | 580 |
| 300 | 136 | 139 | 477 | 487 | 496 | 504 | 512 | 519 | 534 | 547 | 560 |
| 310 | 143,0 | 145,6 | 153,0 | 461 | 471 | 480 | 489 | 497 | 512 | 527 | 540 |
| 320 | 150,1 | 152,5 | 158,8 | 434 | 446 | 457 | 467 | 476 | 492 | 507 | 522 |
| 330 | 157,2 | 159,4 | 165,0 | 404 | 421 | 434 | 445 | 455 | 473 | 489 | 504 |
| 340 | 164,3 | 166,3 | 171,3 | 197,7 | 393 | 411 | 424 | 436 | 456 | 473 | 488 |
| 350 | 171,4 | 173,3 | 177,8 | 198,7 | 333 | — | 405 | 419 | 440 | 458 | 474 |
| 360 | 178,5 | 180,3 | 184,5 | 202 | 249 | — | — | 401 | 426 | 445 | 462 |
| 370 | 185,6 | 187,4 | 191,2 | 206 | 239 | — | — | — | 412 | 433 | 450 |
| 380 | 192,7 | 194,4 | 198,0 | 212 | 238 | 284 | — | — | 400 | 422 | 440 |
| 390 | 199,8 | 201 | 205 | 217 | 239 | 274 | — | — | — | 412 | 431 |
| 400 | 207 | 209 | 212 | 223 | 242 | 270 | — | — | — | 404 | 423 |
| 410 | 214 | 216 | 219 | 229 | 246 | 270 | 299 | 329 | 371 | 398 | 417 |
| 420 | 221 | 223 | 226 | 235 | 251 | 271 | 296 | 323 | 365 | 392 | 412 |
| 430 | 228 | 230 | 233 | 242 | 256 | 274 | 296 | 319 | 360 | 388 | 409 |

| T, °K | Pressure, MPa | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 14 | 16 | 18 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 60 |
| 130 | 1027 | 1028 | 1030 | 1031 | 1036 | 1040 | 1044 | 1048 | 1053 | 1057 | 1069 |
| 140 | 1006 | 1008 | 1011 | 1013 | 1020 | 1026 | 1033 | 1040 | 1046 | 1053 | 1064 |
| 150 | 978 | 981 | 985 | 988 | 997 | 1005 | 1014 | 1022 | 1031 | 1040 | 1057 |
| 160 | 947 | 952 | 956 | 960 | 970 | 980 | 991 | 1001 | 1011 | 1021 | 1041 |
| 170 | 915 | 920 | 925 | 930 | 942 | 953 | 965 | 977 | 988 | 999 | 1022 |
| 180 | 883 | 889 | 894 | 899 | 913 | 926 | 939 | 951 | 964 | 976 | 1001 |
| 190 | 851 | 857 | 863 | 869 | 884 | 898 | 912 | 926 | 940 | 953 | 979 |
| 200 | 820 | 827 | 833 | 840 | 856 | 871 | 886 | 901 | 916 | 930 | 958 |
| 210 | 790 | 797 | 804 | 811 | 828 | 845 | 861 | 877 | 892 | 907 | 937 |
| 220 | 762 | 769 | 777 | 784 | 802 | 819 | 837 | 853 | 869 | 885 | 916 |
| 230 | 734 | 742 | 750 | 758 | 777 | 795 | 813 | 831 | 848 | 864 | 897 |
| 240 | 707 | 716 | 724 | 733 | 753 | 772 | 791 | 809 | 827 | 844 | 878 |
| 250 | 682 | 691 | 700 | 709 | 730 | 750 | 770 | 789 | 807 | 825 | 860 |
| 260 | 658 | 668 | 677 | 686 | 708 | 729 | 750 | 769 | 788 | 807 | 842 |
| 270 | 635 | 645 | 655 | 664 | 687 | 709 | 730 | 751 | 770 | 790 | 826 |
| 280 | 613 | 623 | 634 | 644 | 668 | 691 | 712 | 733 | 754 | 773 | 811 |
| 290 | 592 | 603 | 614 | 624 | 649 | 673 | 695 | 717 | 738 | 758 | 796 |
| 300 | 572 | 583 | 595 | 606 | 631 | 656 | 679 | 701 | 723 | 743 | 782 |
| 310 | 553 | 565 | 577 | 588 | 615 | 640 | 664 | 686 | 708 | 729 | 769 |
| 320 | 535 | 548 | 560 | 571 | 599 | 625 | 649 | 673 | 695 | 716 | 757 |
| 330 | 518 | 531 | 544 | 556 | 584 | 611 | 636 | 660 | 682 | 704 | 746 |
| 340 | 503 | 516 | 529 | 542 | 571 | 598 | 623 | 648 | 671 | 693 | 735 |
| 350 | 480 | 503 | 515 | 528 | 556 | 582 | 607 | 630 | 652 | 674 | 714 |
| 360 | 477 | 491 | 504 | 517 | 546 | 572 | 597 | 621 | 643 | 665 | 706 |
| 370 | 466 | 480 | 494 | 506 | 536 | 563 | 588 | 612 | 635 | 657 | 699 |
| 380 | 456 | 471 | 484 | 497 | 527 | 555 | 581 | 605 | 628 | 651 | 693 |
| 390 | 447 | 462 | 476 | 489 | 520 | 547 | 573 | 598 | 622 | 645 | 688 |
| 400 | 440 | 455 | 469 | 482 | 513 | 541 | 567 | 592 | 616 | 640 | 684 |
| 410 | 434 | 449 | 463 | 476 | 507 | 562 | 587 | 611 | 635 | 640 | 680 |
| 420 | 429 | 444 | 458 | 471 | 502 | 530 | 557 | 582 | 607 | 631 | 677 |
| 430 | 425 | 441 | 454 | 477 | 498 | 526 | 553 | 578 | 603 | 627 | 674 |

saturation line; T, temperature, p, pressure; ρ, density; $p_{cr}$, $\rho_{cr}$, $T_{cr}$, critical parameters; $\omega = \rho/\rho_{cr}$, reduced density; $\tau = T/T_{cr}$, reduced temperature.

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# CALCULATION OF THE THERMODYNAMIC CHARACTERISTICS OF THE SYSTEMS Li—LiH, Li—LiD, AND Li—LiT

É. É. Shpil'rain, K. A. Yakimovich, and E. A. Tsirlina

UDC 536.7

An analysis and generalization of experimental literature data are made on the basis of the properties of the behavior of a system of the Li—LiH type with liquid—vapor equilibrium which were discussed earlier.

The behavior of a system of the Li—LiH type under conditions of liquid—vapor phase equilibrium at a constant temperature was discussed in [1]. The liquid phase consisted of a real solution of Li and LiH while the vapor phase consisted of an ideal-gas mixture of Li, LiH, $H_2$, $Li_2$, and $Li_2H$.

A series of equations were obtained for calculating the thermodynamic properties of such systems in the presence of the heterogeneous reaction

$$LiH_{(l)} \rightleftarrows Li_{(l)} + 1/2H_{2\,(g)} \tag{1}$$

In particular, the following equations were obtained for the activity coefficients of the components of the liquid phase, neglecting the influence of the pressure on the properties of the liquid (for T = const, x < 1):

for lithium

$$\ln\gamma_1 = -xF + \int_0^x F dx, \tag{2}$$

for lithium hydride

$$\ln\gamma_2 = (1-x)F + \int_0^x F dx - \ln K. \tag{3}$$

Here x is the molar fraction of lithium hydride in the liquid solution; $F = \ln\left(\frac{1-x}{x} p_3^{1/2}\right)$; K is the equilibrium constant of the reaction (1), a function of the temperature,

Institute of High-Temperatures, Academy of Sciences of the USSR, Moscow. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 38, No. 2, pp. 249-260, February, 1980. Original article submitted September 4, 1979.

0022-0841/80/3802-0151$07.50 © 1980 Plenum Publishing Corporation 