IPPJ-AM-10

CHARGE CHANGING CROSS SECTIONS FOR HEAVY-PARTICLE COLLISIONS IN THE ENERGY RANGE FROM 0.1 eV TO 10 MeV

II. INCIDENCE OF C, N, O AND THEIR IONS

K. OKUNO

INSTITUTE OF PLASMA PHYSICS
NAGOYA UNIVERSITY

NAGOYA, JAPAN

IPPJ–AM–10

CHARGE CHANGING CROSS SECTIONS FOR HEAVY-PARTICLE COLLISIONS IN THE ENERGY RANGE FROM 0.1 eV TO 10 MeV

II. INCIDENCE OF C, N, O AND TEHIR IONS

Kazuhiko Okuno

Department of Physics, Tokyo Metropolitan University,
Setagayaku, Tokyo 158, Japan

December 1978

Charge Changing Cross Sections for Heavy-particle Collisions in the Energy Range from 0.1 eV to 10 MeV

II. Incidence of C, N, O and their ions

Kazuhiko OKUNO

Department of Physics, Tokyo Metropolitan University,
Setagayaku, Tokyo 158, Japan

Introduction

This paper presents a compilation of the experimental works on charge changing cross sections for neutral atoms, negative- and positive-atomic ions of atomic numbers Z = 6 - 8 in collisions with atoms and simple molecules. A systematic survey of the literature has been made through October 1977. Some recent data are also included. The result is summarized in graphical forms with reference lists attached.

Note on Reference List and Graphs

There are some review articles[1-7] on the charge changing cross sections of atoms and ions in gases. Generally, they deal with the electron loss cross sections of projectiles and the ionization cross sections of targets. The energy ranges are rather high, where the electron capture processes are not dominant. Here we compile the experimental works on the charge changing cross sections of projectiles in a wide energy range down to 0.1 eV. In the low-energy region, the electron capture process becomes dominant. The charge changing cross section data on hydrogen atom and ion in various gases and vapors were covered by Tawara and Russek[6] and Tawara[7], so that they are not included here.

Some review papers[1,6] have already discussed fully about the charge changing process, experimental methods and accuracy of the data. Here only the explanation of the symbols used in this paper is described.

In the charge changing process, an atomic projectile colliding with atomic or molecular targets may capture or lose one or more electrons at the collision. The process can be written as

$$A^{i+} + B \rightarrow A^{j+} + B^{k+} + (j+k-i)\ e\ , \qquad (1)$$

irrespective of the excitation of the colliding particles. Here, i,j and k are the initial and final charge states of the projectile (A) and the final state of the target (B), respectively. Then (j+k-i) electrons are released after the collision. Of course, i,j and k cannot be larger than the atomic numbers of the respective particles and $j+k-i \geq 0$. The elementary cross section of the

process (1) is represented by σ_{ij}^{0k} (or $\sigma_{ij}^{0(k0)}$ for a diatomic molecular target to be dissociated). The summation over k of the elementary cross sections, $\sigma_{ij} \equiv \sum_k \sigma_{ij}^{0k}$, means the charge changing cross section of the projectile when i is not equal to j: σ_{ij} $(i > j)$ is the electron capture cross section and σ_{ij} $(i < j)$ is the electron loss cross section. When j = i, the cross section σ_{ii} means the total pure ionization cross section of the target particle and is denoted by $\sigma_i^i \equiv \sum_k \sigma_{ii}^{0k}$. In the condenser method using parallel plates, the cross sections of slow ion and electron productions are obtained. They are denoted by $\sigma_i^+ \equiv \sum_{jk} k\, \sigma_{ij}^{0k}$ and $\sigma_i^- \equiv \sum_{jk} (j+k-i)\sigma_{ij}^{0k}$, including ionization of projectiles. The cross sections obtained by the condenser method or projectile-beam attenuation method are some sort of sum of the elementary cross sections. Therefore, one cannot determine the charge changing cross section only by the total charge collection or the beam attenuation unless sufficient information about the charge changing mechanism is available.

In this paper, experimental data are divided into three groupes: (A) Electron capture cross sections of projectile, (B) Electron loss cross sections of projectile, and (C) Ionization cross sections of target and production cross sections of slow ions and electrons. Some of the literature dealing with excited states, angular distribution of scattered particles, energy loss spectra of the projectile and so on, rather than cross sections themselves, are also included in the present lists and tables. The graphs are separated into two energy ranges: from 0.1 eV to 1.0 keV and 1.0 keV to 10 MeV. The energy scale is given in the laboratory

systems. For the data on isotopes, the energy scale has been corrected by multiplying a scale factor. The cross sections obtained for molecular targets are all presented in the unit of cm^2 per molecule in this paper.

The present author should like to thank W. Shearer-Izumi and T. Watanabe (Faculty of Engineering, University of Tokyo) for the proffer of their reference library (1967-1975) and also should like to thank K. Takayanagi (Institute of Space and Aeronautical Science, University of Tokyo) for making his bibliographies[8,9] available.

References

1) S.K. Allison, Rev. Mod. Phys. 30 1137 (1958).
2) H.D. Betz, Rev. Mod. Phys. 44 465 (1972).
3) R.C. Dehmel, H.K. Chau and H.H. Fleishmann, Atomic Data 5 231 (1973).
4) H.H. Lo and W.L. Fite, Atomic Data 1 305 (1970).
5) V.S. Nikolaev, Sov. Phys.-Uspekhi 8 269 (1965).
6) H. Tawara and A. Russek, Rev. Mod. Phys. 45 179 (1973).
7) H. Tawara, IPPJ-AM-1, IPPJ/Nagoya University, Nagoya (1977).
8) K. Takayanagi, Atomic collisions: Bibliography No.5, Ionic impact (experimental) 1923-1965, RGAMP-Bibl. 2, ISAS/University of Tokyo (1967).
9) K. Takayanagi, Atomic collisions: Bobliography No.6, Ionic impact (experimental) suppl. through 1967, RGAMP-Bibl. 3, ISAS/University of Tokyo (1968).

Charge Changing Cross Sections of Carbon Atoms and Ions, Z=6

I. Lists of Reference

II. Tables of Experimental Data

A) Electron Capture Cross Sections

B) Electron Loss Cross Sections

C) Cross Sections of Ionization, Slow ions Productions and Electron productions

III. Graphs of Charge Changing Cross Sections

I. References for Experimental Data of C (Z=6)

1. V.A.Belyaev, B.G.Brezhnev and E.M.Erastov, Sov. Phys. JETP 27, 924 (1968)

2. B.Cobic, M.Vujovic and M.Matic, J. Phys. B 3, 374 (1970)

3. D.H.Crandall, Proc. 9th ICPEAC,Seattle (1975) p.190

4. D.H.Crandall, M.L.Mallory and D.C.Kocher, Phys. Rev. A. 15, 61 (1977)

5. D.H.Crandall, Phys. Rev. A 16, 958 (1977)

6. I.S.Dmitriev, V.S.Nikolaev, L.N.Fateeva and Y.A.Teplova, Sov. Phys. JETP 15, 11 (962)

7. I.S.Dmitriev, V.S.Nikolaev, L.N.Fateeva and Y.A.Teplova, Sov. Phys. JETP 16, 259 (1963)

8. I.S.Dmitriev, V.S.Nikolaev, Ya.A.Teplova, B.M.Popov and L.I.Vinogradova, Sov. Phys. JETP 23, 832 (1966)

9. I.S.Dmitriev, V.S.Nikolaev, Ya.A.Teplova and B.A. Prigodin, Proc. 6th ICPEAC,Cambridge, (1969) p.460

10. I.S.Dmitriev, V.S.Nikolaev and Ya.A.Teplova, Proc. 7th ICPEAC,Amsterdam, (1971) p.510

11. I.S.Dmitriev, Ya.A.Teplova and V.S.Nikolaev, Sov. Phys. JETP 34, 723 (1972)

12. I.S.Dmitriev, V.S.Nikolaev, Yu.A.Tashaev and Ya.A. Teplova, Sov. Phys. JETP 40, 1017 (1975)

13. B.A.Dyachkov and V.I.Zinenko, Sov. Phys. Tech. Phys. 18, 1087 (1974)

14. F.C.Fehsenfeld, A.L.Schmeltekopf and E.E.Ferguson, J. Chem. Phys. 45, 23 (1966)

15. Ya.M.Fogel', R.V.Mitin and A.G.Koval', Sov. Phys. JETP 4, 359 (1957)

16. Ya.M.Fogel', L.I.Krupnik, A.G.Koval' and R.P. Slabospitskii, Sov. Phys. Tech. Phys. 2, 902 (1957)

17. Ya.M.Fogel', V.A.Ankudinov, D.V.Pilipenko and N.V. Topolia, Sov. Phys. JETP 7, 400 (1958)

18. Ya.M.Fogel', V.A.Ankudinov and D.V.Pilipenko, Sov. Phys. JETP 8, 601 (1959)

19. Ya.M.Fogel', Usp. Fiz. Nauk. 69, 243 (1960)

20. H.B.Gilbody and J.B.Hasted, Proc. Roy. Soc. A239, 334 (1956)

21. J.Goldhar, R.Mariella,Jr. and A.Javan, Appl. Phys. Lett. 29, 96 (1976)

22. J.B.Hasted, Proc. Roy. Soc. A205, 421 (1951)

23. J.B.Hasted and R.A.Smith, Proc. Roy. Soc. A235, 349 (1956)

24. J.B.Hasted and R.A.Smith, Proc. Roy. Soc. A235, 354 (1956)

25. J.B.Hasted, S.M.Iqbal and M.M.Yousaf, Proc. 7th ICPEAC, Amsterdam, (1971) p.126

26. J.B.Hasted, S.M.Iqbal and M.M.Yousaf, J. Phys. B4, 343 (1971)

27. R.N.Il'in, I.T.Serenkov and V.A.Oparin, Proc. 9th ICPEAC, Seattle, (1975) p.39

28. M.Matic and B.Cobic, J. Phys. B4, 111 (1971)

29. V.S.Nikolaev, L.N.Fateeva, I.S.Dmitriev and Ya.A. Teplova, Sov. Phys. JETP 13, 695 (1961)

30. V.A.Oparin, R.N.Il'in, I.T.Serenkov, E.S.Solovyev and N.V.Fedorenko, Proc. 7th ICPEAC, Amsterdam, (1971) p.796

31. J.H.Ormrod and W.L.Michel, Canad. J. Phys. 49, 606 (1971)

32. D.V.Pilipenko and Ya.M.Fogel', Sov. Phys. JETP 17, 1222 (1963)

33. A.Salop and R.E.Olson, Proc. 9th ICPEAC, Seattle, (1975) p.99

34. I.T.Serenkov, R.N.Il'in, V.A.Oparin and E.S.Solov'ev, Zh. Eksp. Teor. Fiz. 68, 1686 (1975)

35. C.W.Sherwin, Phys. Rev. 57, 814 (1940)

36. T.Tonuma, Y.Miyazawa, T.Karasawa and I.Kohno, Japan J. Appl. Phys. 9, 1306 (1970)

37. M.Vujovic, M.Matic and B.Cobic, Proc. 6th ICPEAC, Cambridge, (1969) p.1020

38. H.J.Zwally and D.W.Koopman, Proc. 6th ICPEAC, Cambridge, (1969) p.1025

39. H.J.Zwally and D.W.Koopman, Phys. Rev. A2, 1851 (1970)

II. Tables of Experimental Data

A) Electron Capture Cross Sections of Carbon Atom and Positive Ions; C°, C^{+}, C^{2+}, C^{3+}, C^{4+} and C^{6+}.

(σ_{01})

Fogel' et al.	1959	10,000-65,000	H_2,He,N_2,O_2, Ne,Ar,Kr,Xe	18
Pilipenko, Fogel'	1963	15,000-36,000	CO	32
Dmitriev et al.	1966	410,000	He,N_2,Ar	8
Vujovic et al.	1969	20,000	Kr	37
Ormrod, Michel	1971	20,000-80,000	N_2,Ar	31

(σ_{10})

Sherwin	1940	6,000-24,000	H_2,He	35
Hasted	1951	25-900	Xe	22
Gilbody, Hasted	1956	10-4,000	H_2,Ar,Kr,Xe	19
Fehsenfeld et al.	1966	300°K	O_2,CO_2	14
Belyaev et al.	1968	7-100	C	1
Ormrod, Michel	1971	15,000-80,000	N_2,Ar	31

(σ_{11})

Fogel' et al.	1957	10,000-55,000	H_2,He,N_2,Ne, Ar,Kr	15
Fogel'	1960	5,000-60,000	Kr	19
Dmitriev et al.	1966	410,000	He,N_2,Ar	8
Vujovic et al.	1969	5,000-30,000	N_2,Kr	37
Cobic et al.	1970	5,000-30,000	Kr	2

(σ_{21})				
Sherwin	1940	6,000-24,000	H_2,He	35
Hasted, Smith	1956	1,000-3,000	He,Ne,Ar	23
Ormrod, Michel	1971	40,000-90,000	N_2,Ar	31
Hasted et al.	1971	1,000-3,000	He,Ne,Ar	26
(σ_{32})				
Nikolaev et al.	1961	4,000,000	He,N_2	29
Crandall et al.	1977	10,000-90,000	H_2	4
(σ_{43})				
Nikolaev et al.	1961	4,000,000	He,N_2	29
Zwally, Koopman	1969	1,000-40,000	He,Ne,Ar	38
Zwally, Koopman	1970	400-40,000	He,Ne,Ar	39
Dmitriev et al.	1975	4,000,000	He,N_2	12
Goldhar et al.	1976	1,000	He	21
Crandall et al.	1977	22,800-70,000	H_2	4
Crandall	1977	22,800-90,000	He,Ne,Ar	5
(σ_{42})				
Dmitriev et al.	1975	4,000,000	He,N_2	12
Crandall et al.	1977	20,000-60,000	H_2	4
Crandall	1977	15,600-90,000	He,Ne,Ar	5
(σ_{65})				
Tonuma et al.	1970	39,000-78,000	N_2	36

B) Electron Loss Cross Sections of Carbon Negative Ion, Atom and Postive Ions; C^-, C°, C^+, C^{3+}, C^{4+}, C^{5+}.

($\sigma_{\bar{1}0}$)

Dmitriev et al.	1966	410,000	He,N_2,Ar	8
Ormrod, Michel	1971	25,000-75,000	N_2,Ar	31
Matic, Cobic	1971	5,000-30,000	Ne,Ar,Kr,Xe	28
Il'in et al.	1975	30,000-158,000	Mg	27

($\sigma_{\bar{1}1}$)

Dmitriev et al.	1966	410,000	He,N_2,Ar	8
Matic, Cobic	1971	5,000-30,000	Ne,Ar,Kr,Xe	28

($\sigma_{\bar{1}2}$)

Dmitriev et al.	1966	410,000	He,N_2,Ar	8
Matic, Cobic	1971	5,000-30,000	Ne,Ar,Kr,Xe	28

(σ_{01})

Fogel' et al.	1959	10,000-65,000	H_2,He,N_2,O_2, Ne,Ar,Kr,Xe	18
Pilipenko, Fogel'	1963	15,000-36,000	CO	32
Ormrod, Michel	1971	15,000-85,000	N_2,Ar	31

(σ_{12})

Dmitriev et al.	1966	410,000	He,N_2,Ar	8

(σ_{13})

Dmitriev et al.	1966	410,000	He,N_2,Ar	8

(σ_{14})				
Dmitriev et al.	1966	410,000	Ar,N_2,He	8
(σ_{34})				
Dmitriev et al.	1962	4,000,000	He,N_2	6
(σ_{35})				
Dmitriev et al.	1963	4,000,000	He,N_2	7
(σ_{45})				
Dmitriev et al.	1962	4,000,000	He,N_2	6
Tonuma et al.	1970	39,000-78,000	N_2	36
Dmitriev et al.	1975	4,000,000	He,N_2	22
(σ_{56})				
Tonuma et al.	1970	39,000-78,000	N_2	36

C) Ionization Cross Sections by Carbon Ions

(σ_1^i, σ_1^+, σ_1^-)				
Gilbody, Hasted	1956	10,000-40,000	H_2,Ar,Kr,Xe	18
Sherwin	1940	6,000-24,000	H_2,He,N_2,O_2, Ne,Ar,Kr,Xe	35
(σ_2^i)				
Sherwin	1940	6,000-24,000	H_2,He,N_2,O_2, Ne,Ar,Kr,Xe	35

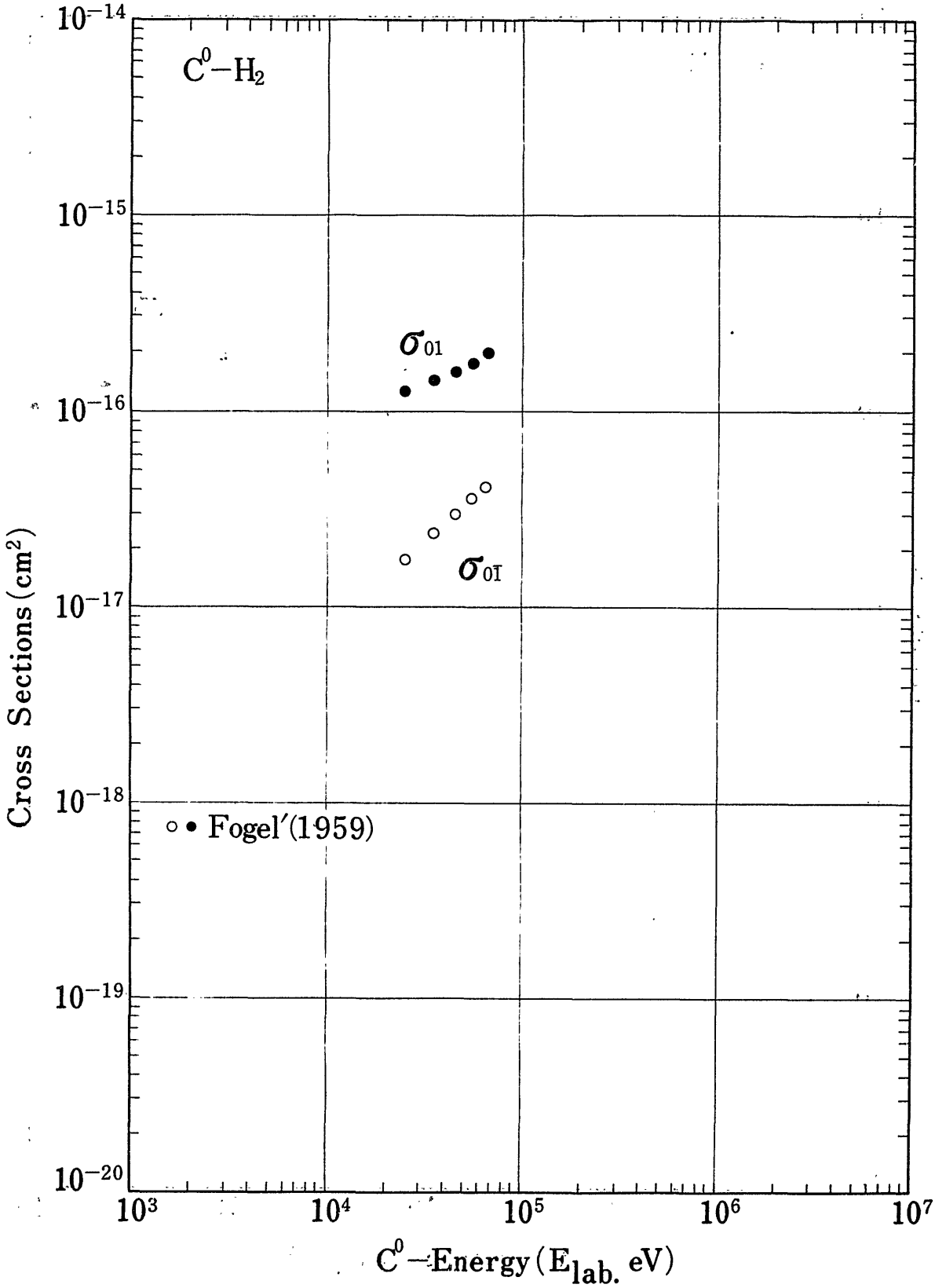


Fig.1 Charge Changing Cross Sections of C^0 in H_2

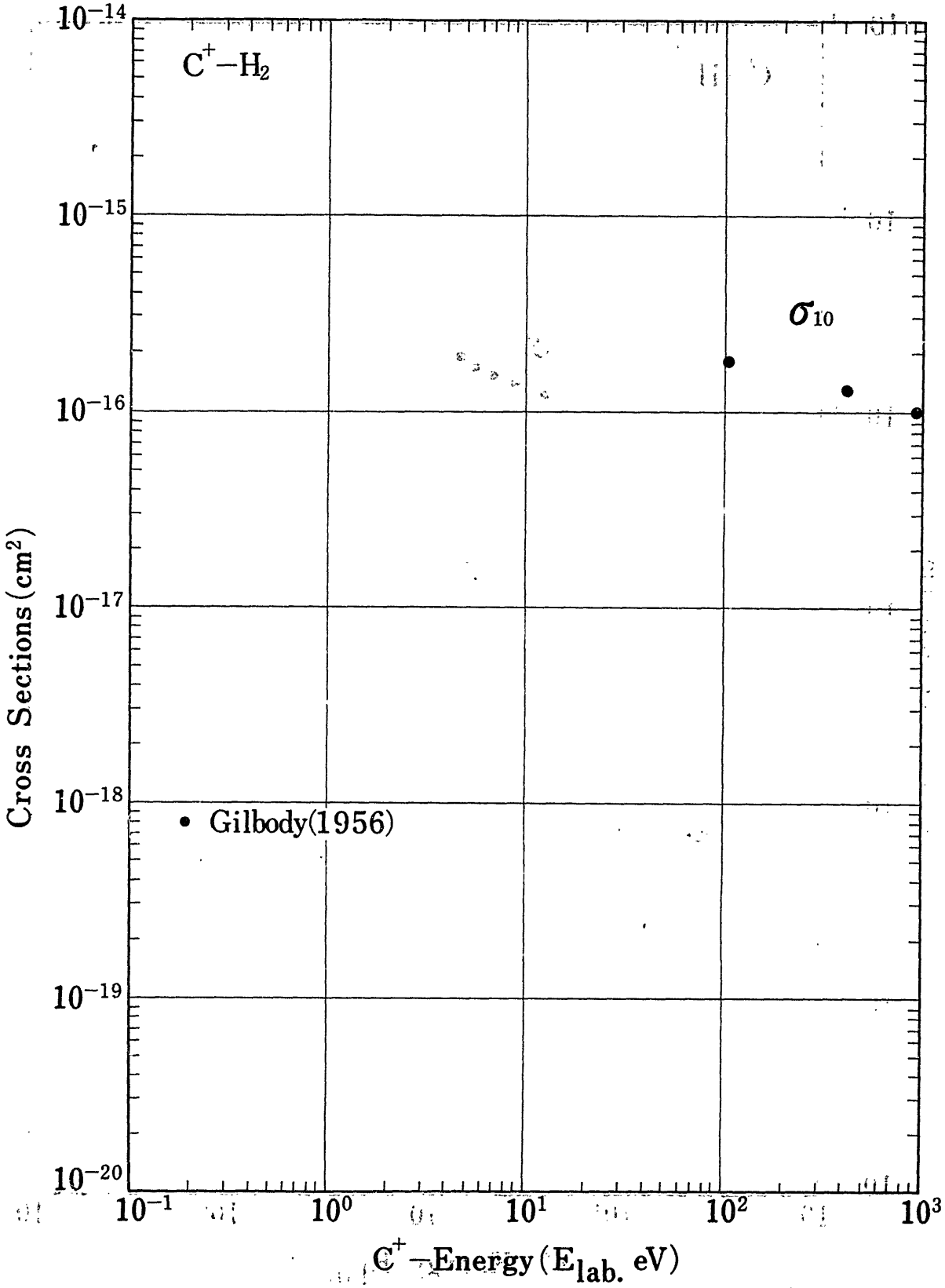


Fig.2-a Charge Changing Cross Sections of C^+ in H_2

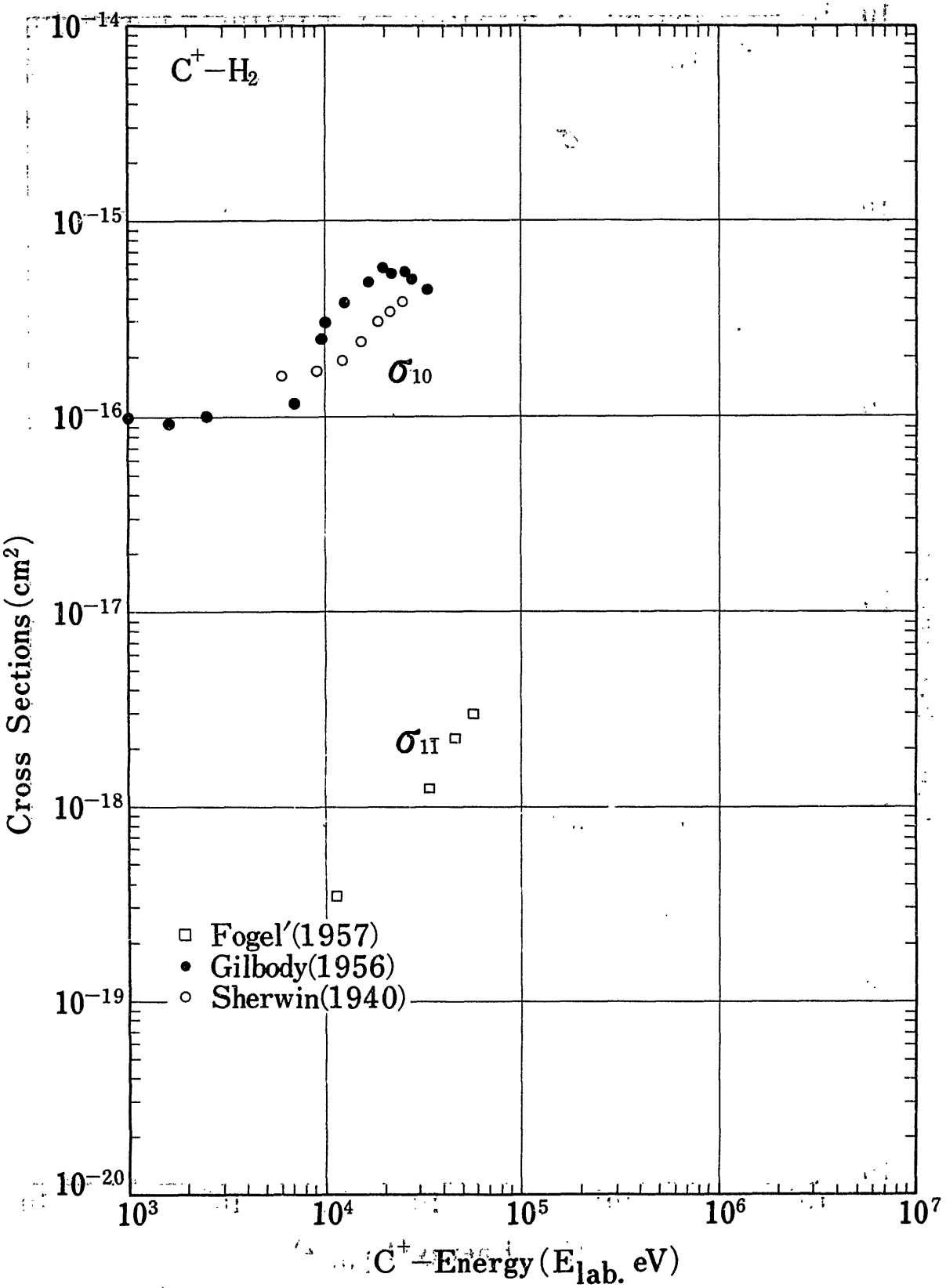


Fig. 2-b Charge Changing Cross Sections of C^+ in H_2

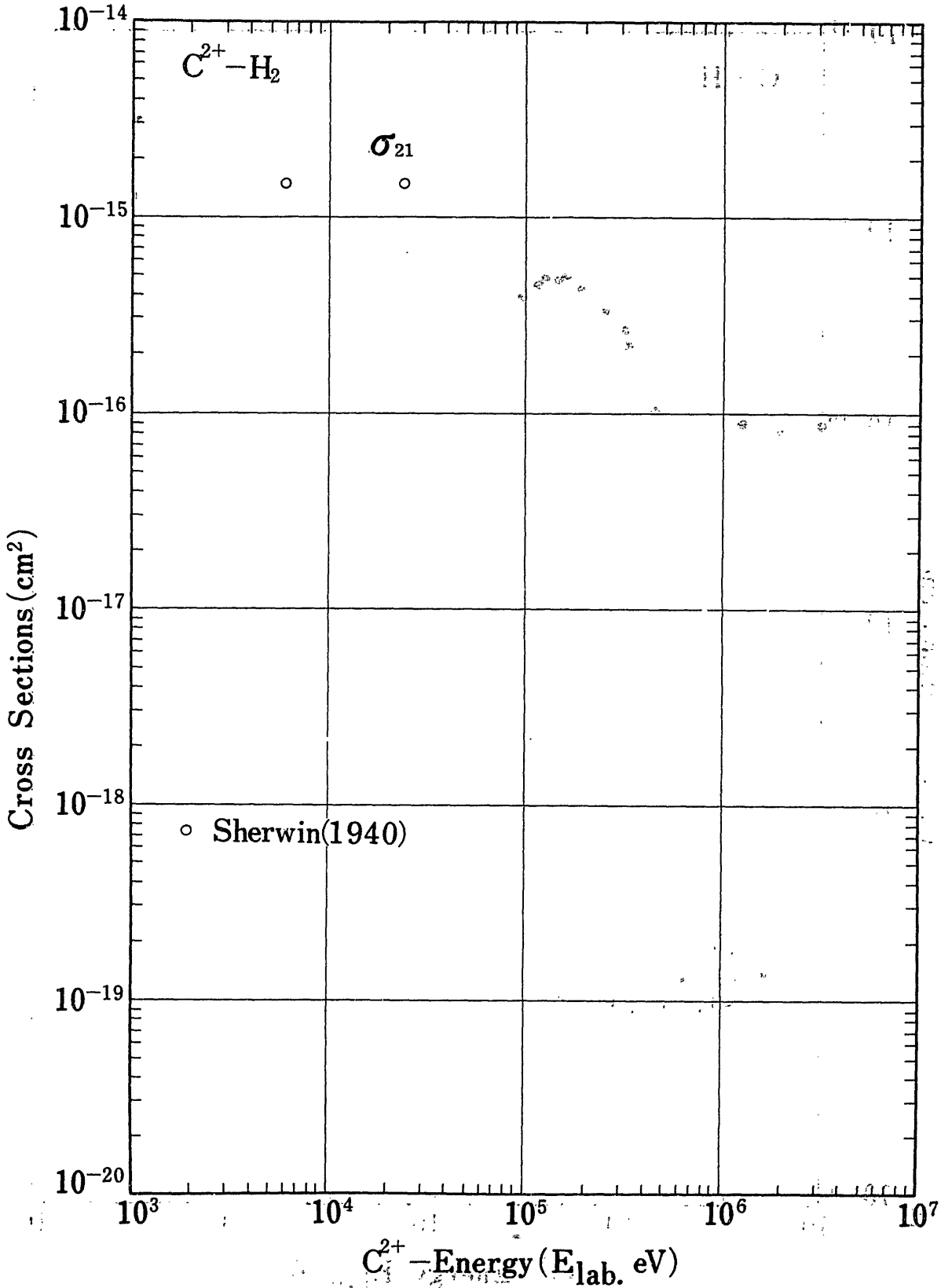


Fig. 3 Charge Changing Cross Sections of C^{2+} in H_2

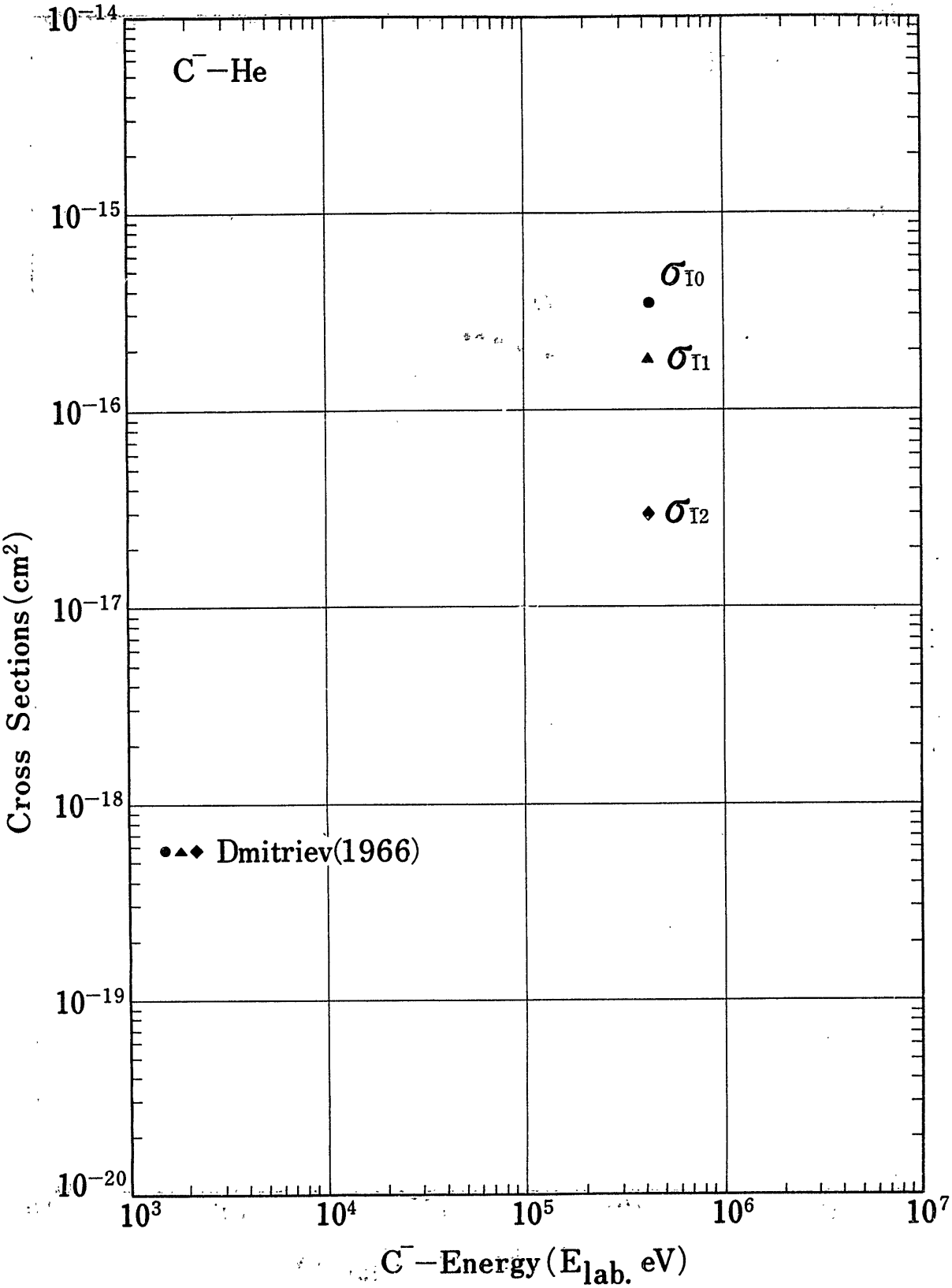


Fig.4 Charge Changing Cross Sections of C^- in He

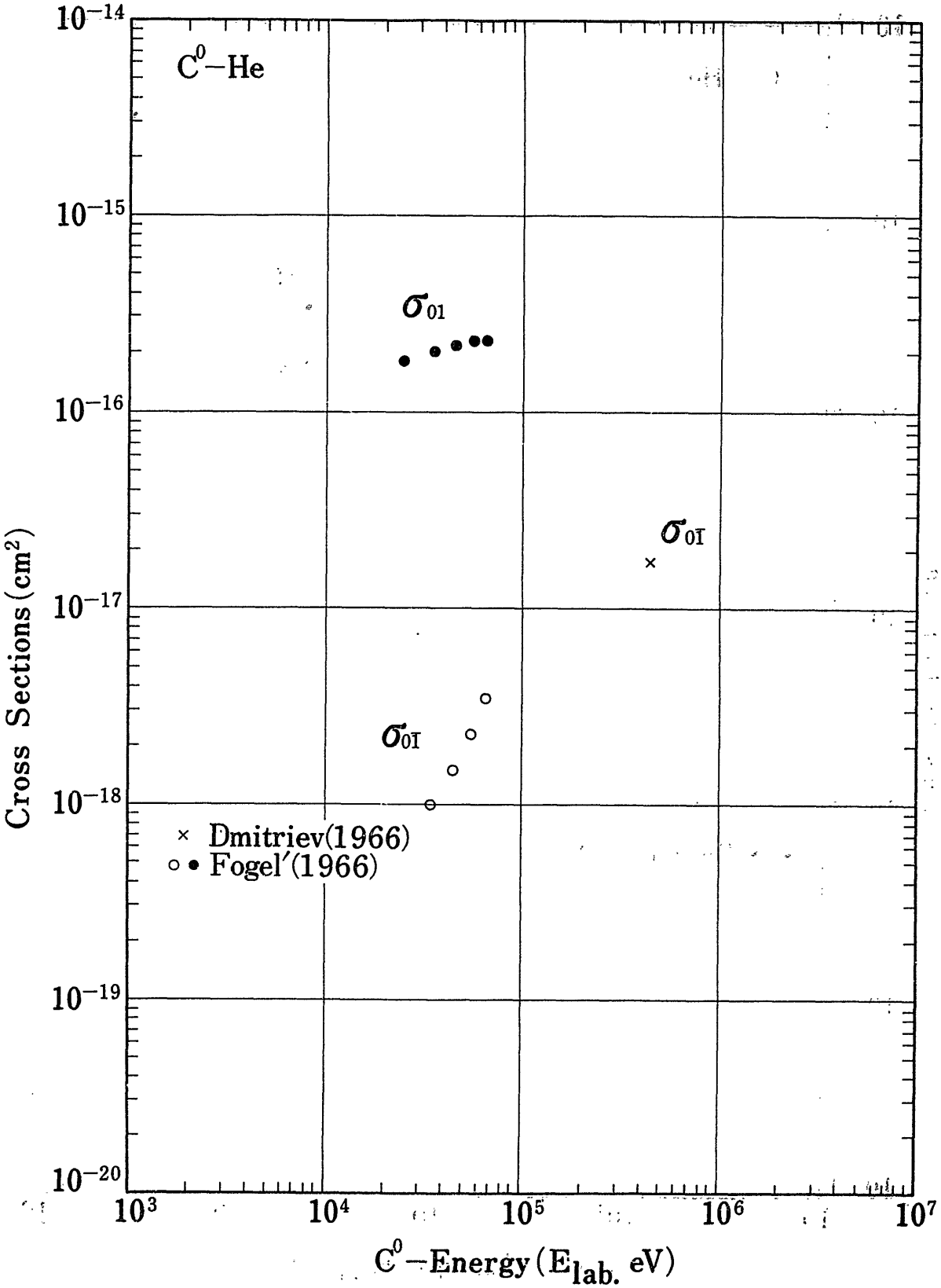


Fig.5 Charge Changing Cross Sections of C^0 in He

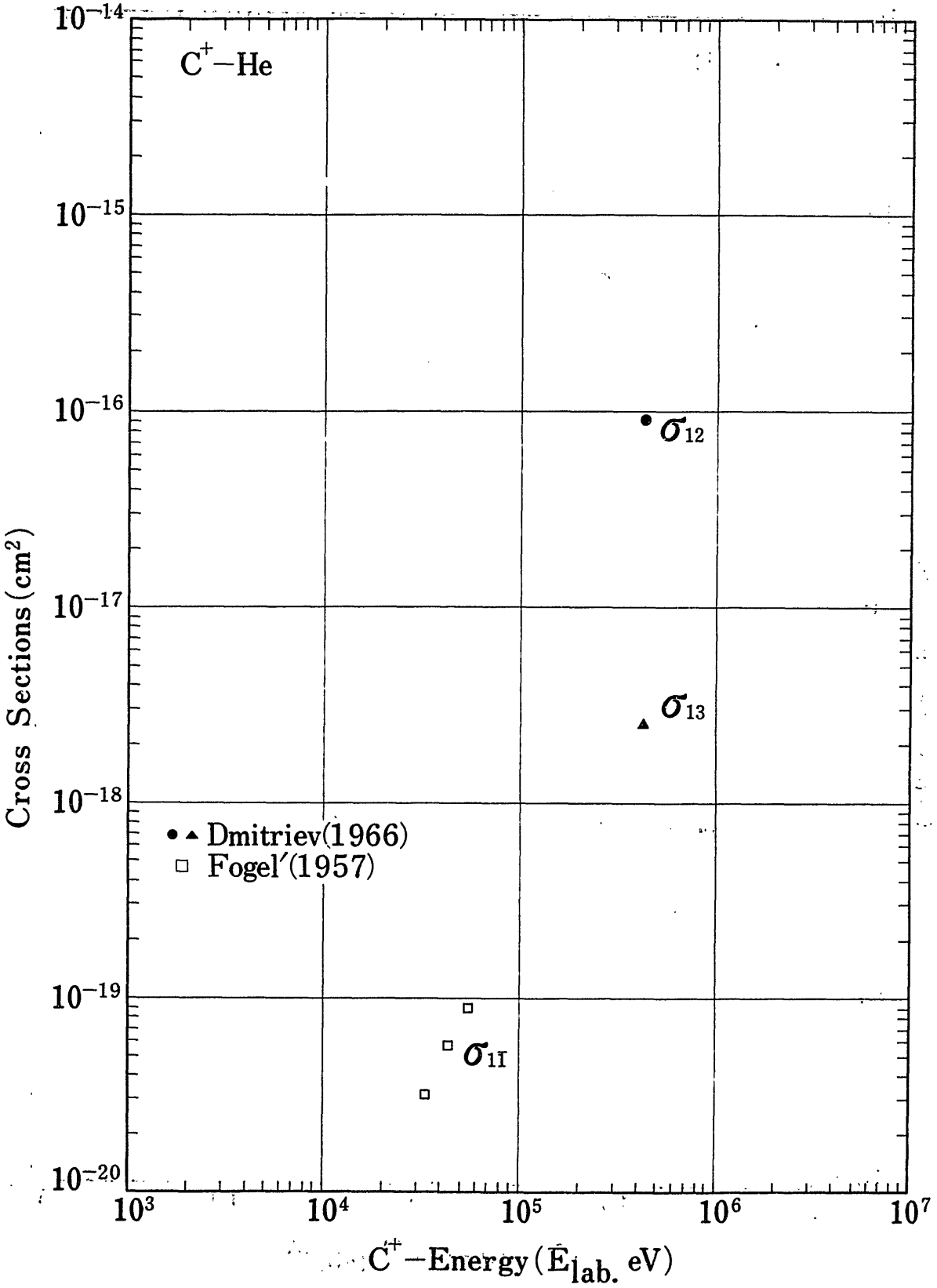


Fig.6 Charge Changing Cross Sections of C^+ in He

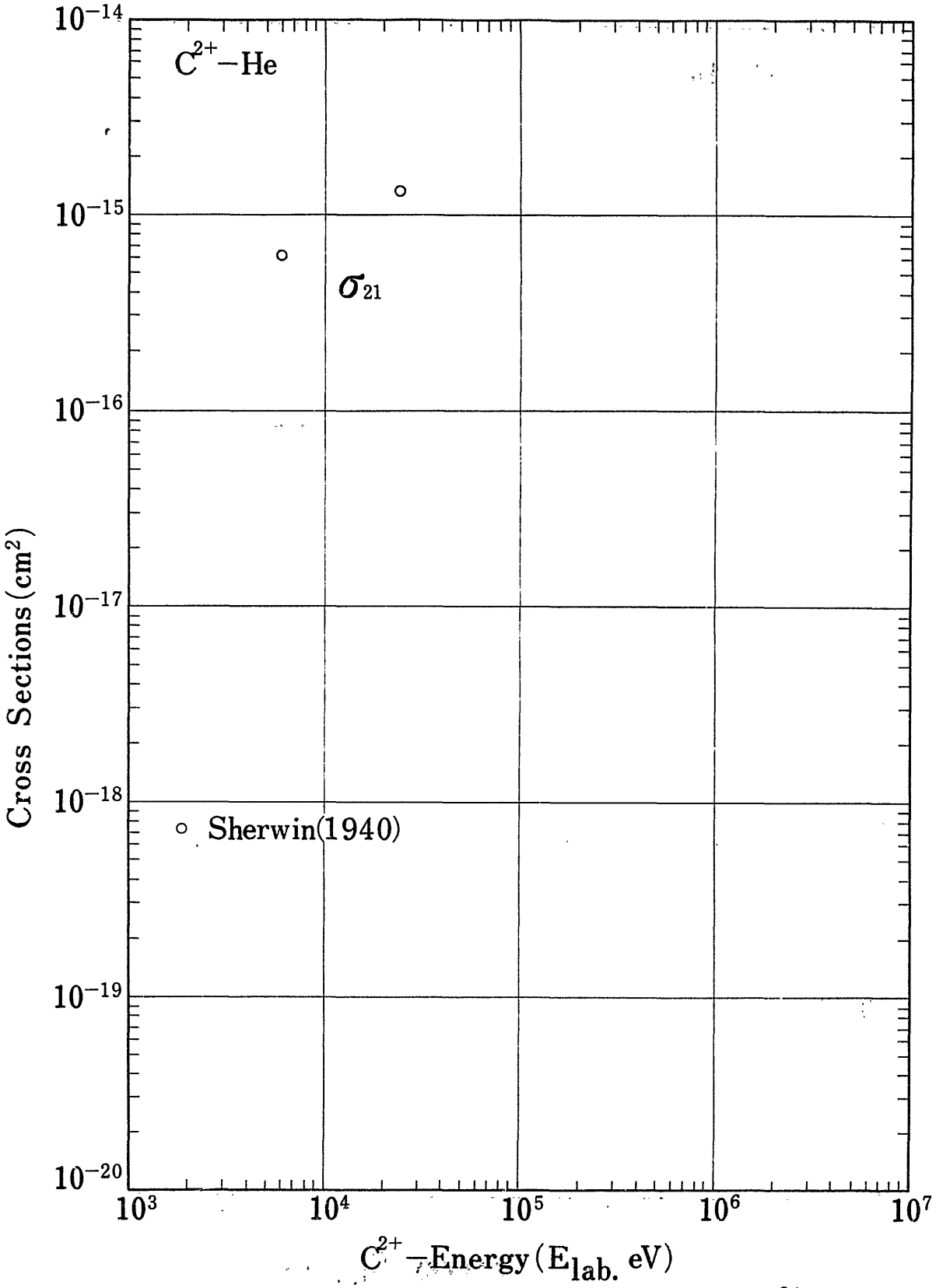


Fig. 7 Charge Changing Cross Sections of C^{2+} in He

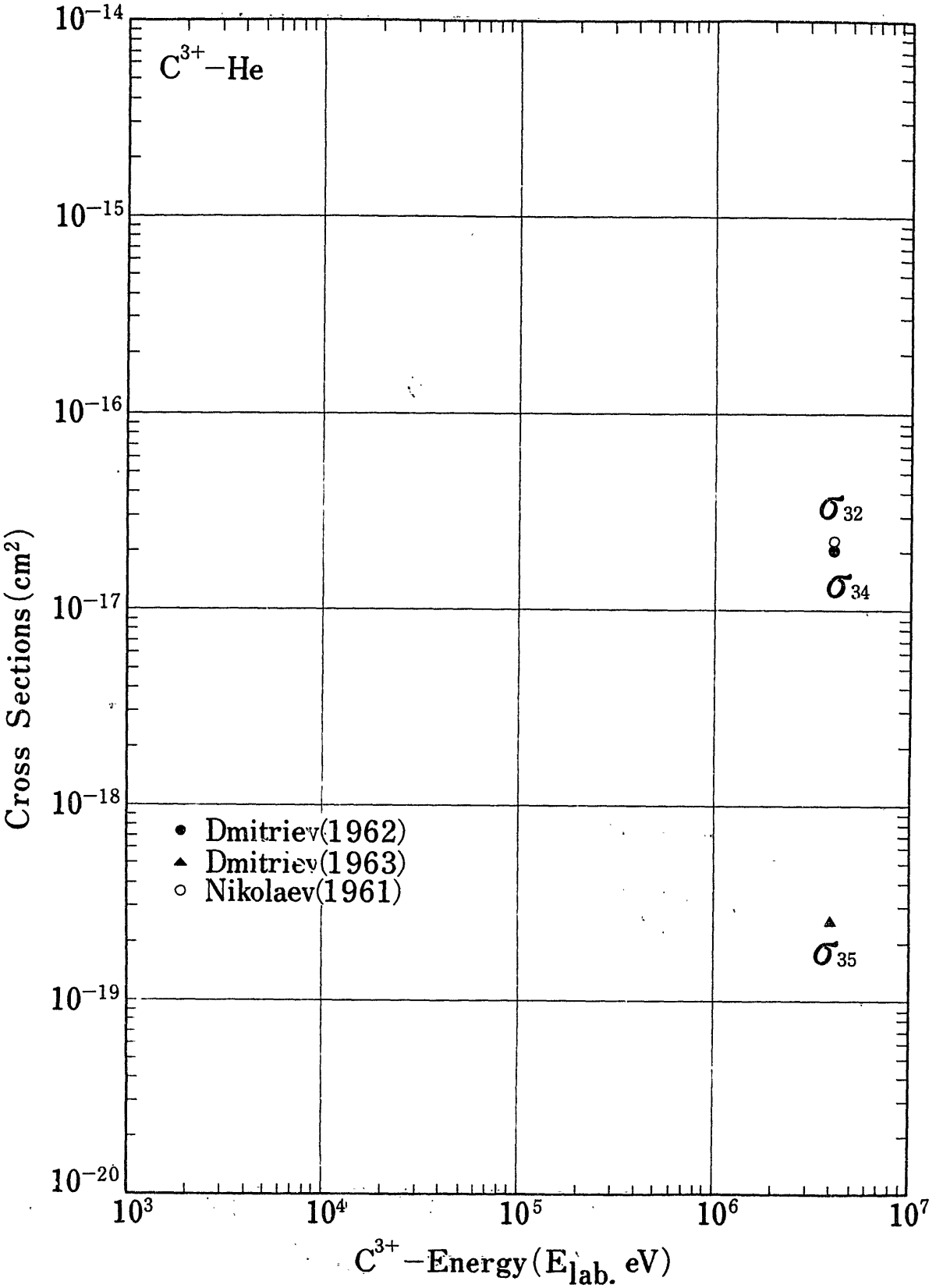


Fig. 8 Charge Changing Cross Sections of C^{3+} in He

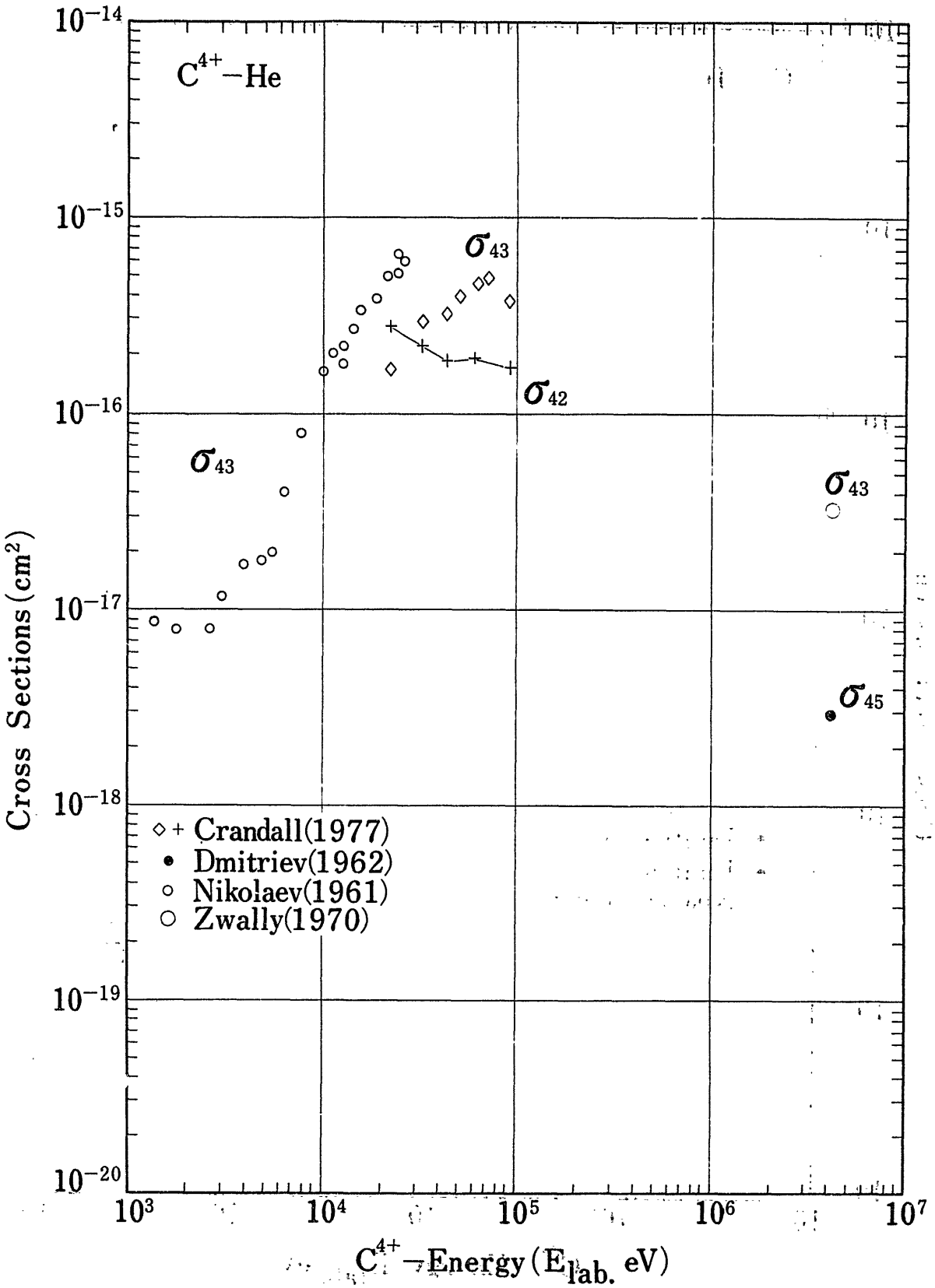


Fig. 9 Charge Changing Cross Sections of C^{4+} in He

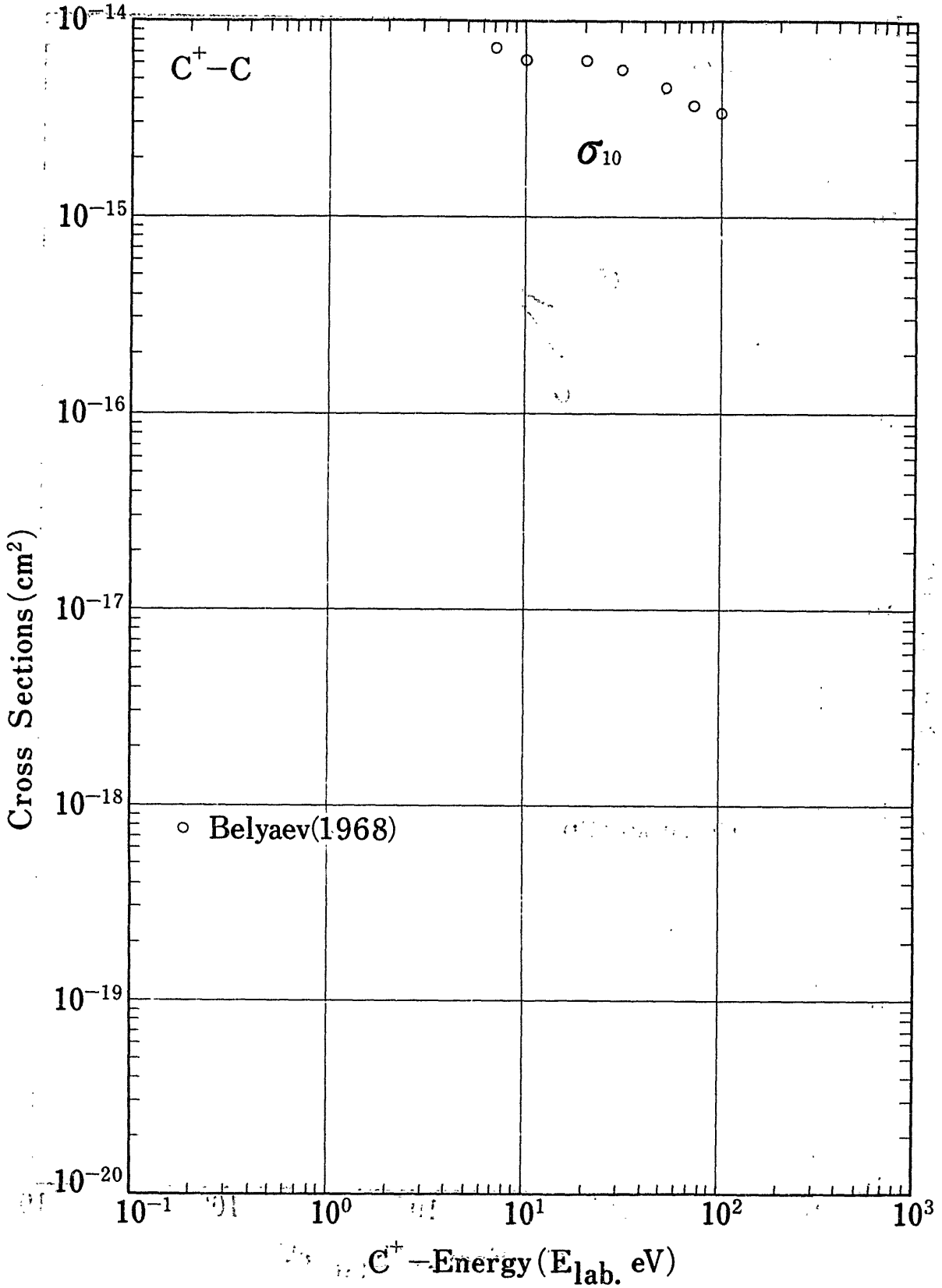


Fig.10 Charge Changing Cross Sections of C^+ in C

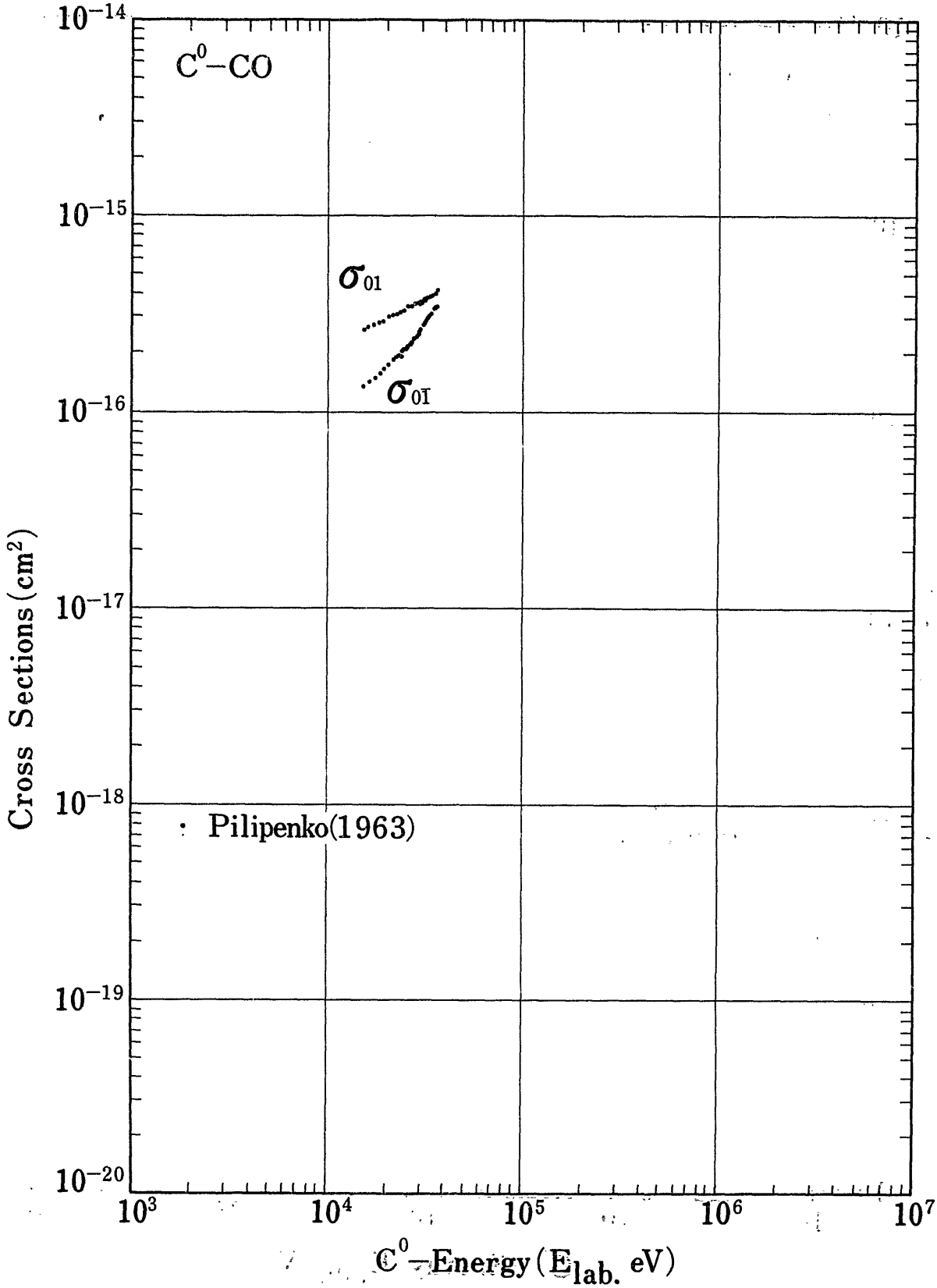


Fig.11 Charge Changing Cross Sections of C^0 in CO

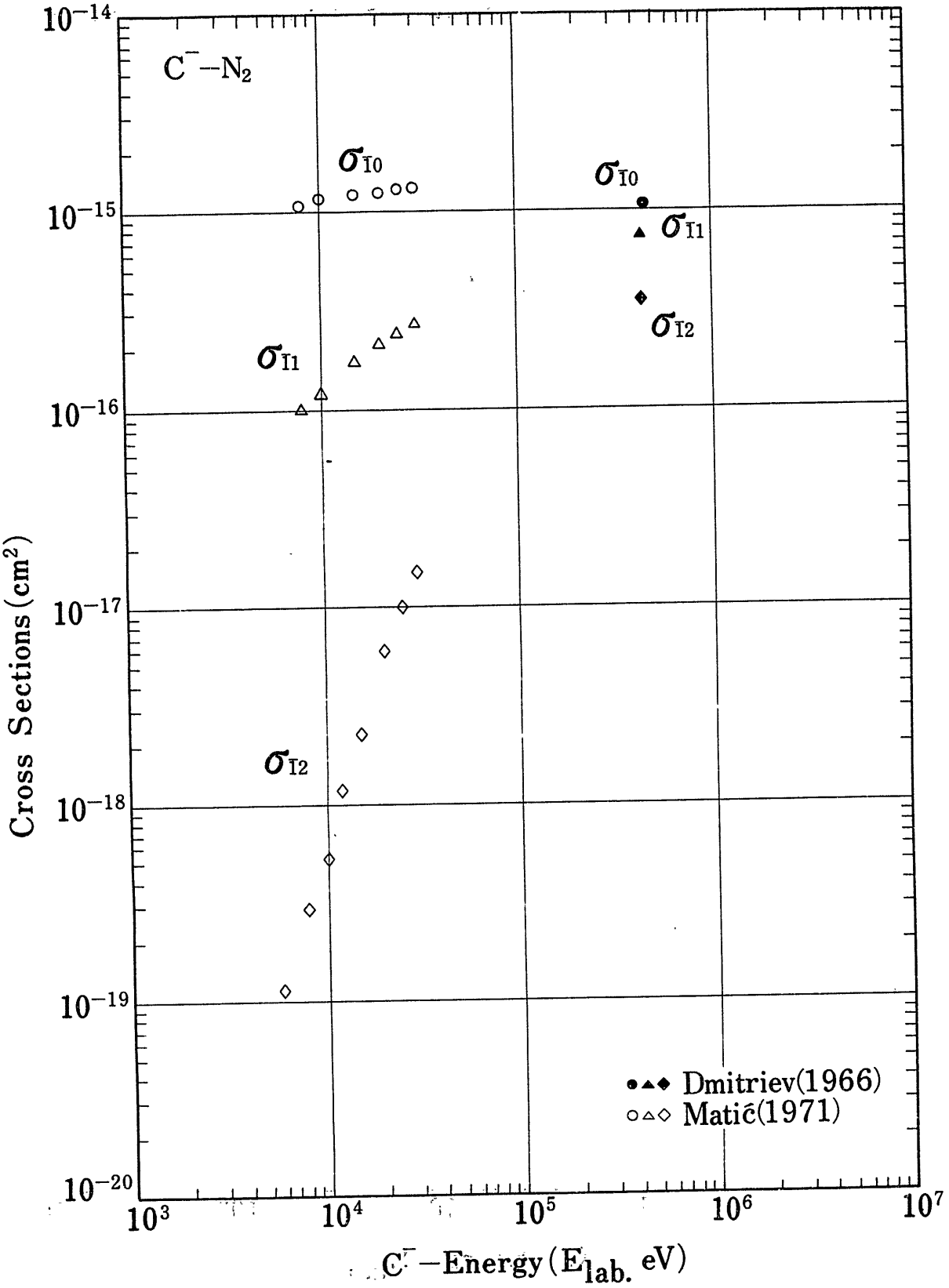


Fig.12 Charge Changing Cross Sections of C^- in N_2

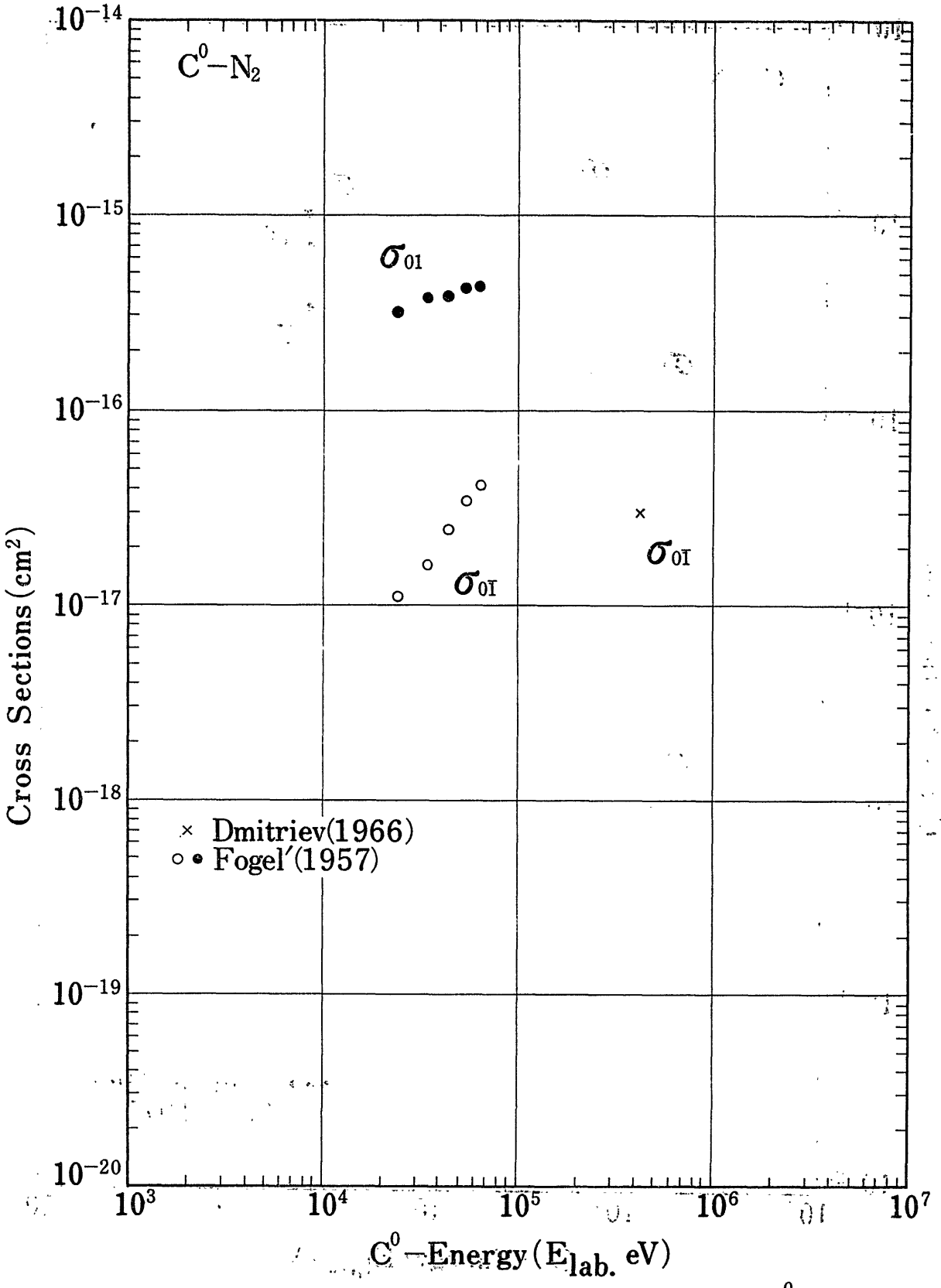


Fig. 13 Charge Changing Cross Sections of C^0 in N_2

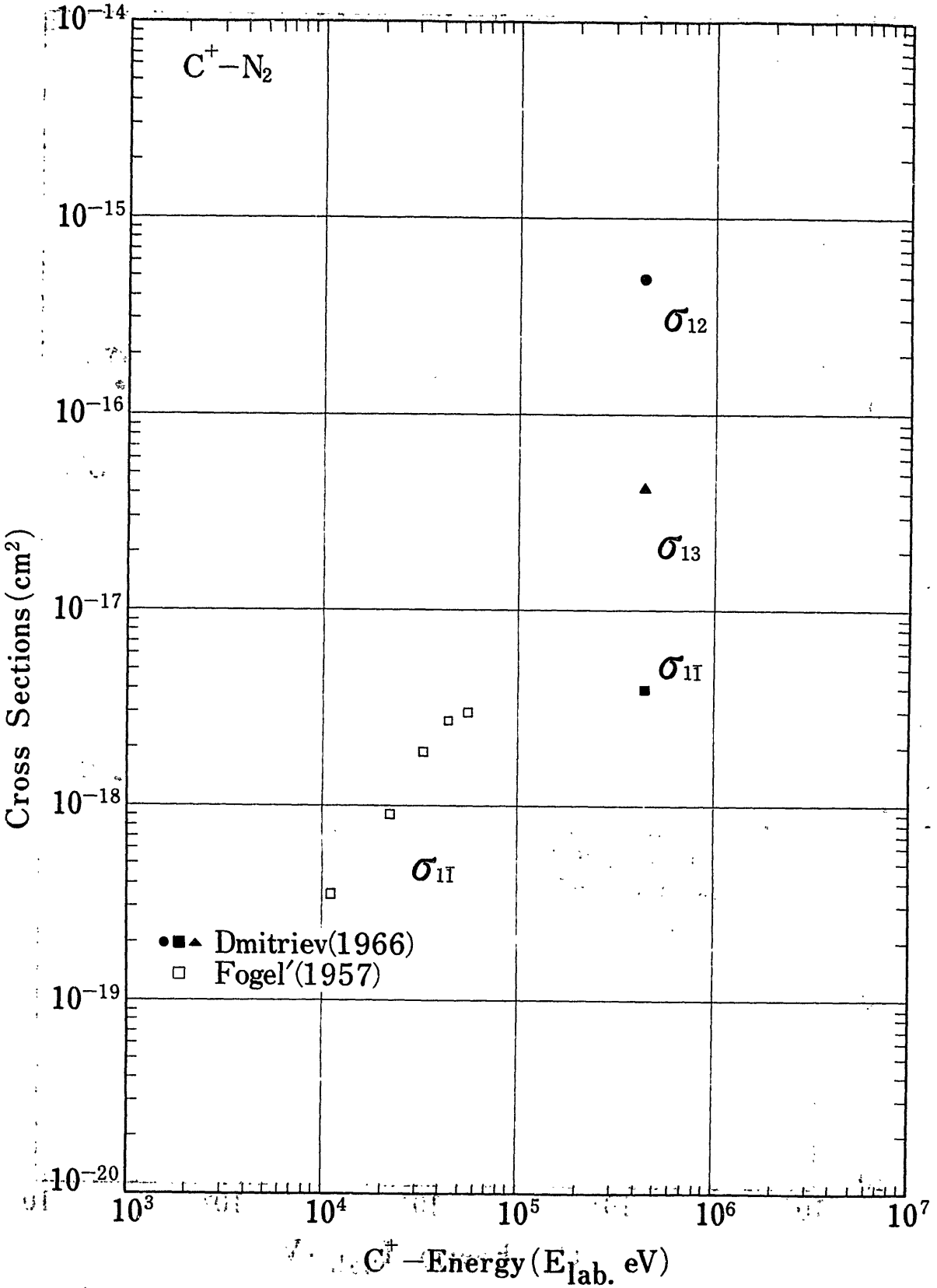


Fig.14 Charge Changing Cross Sections of C^+ in N_2

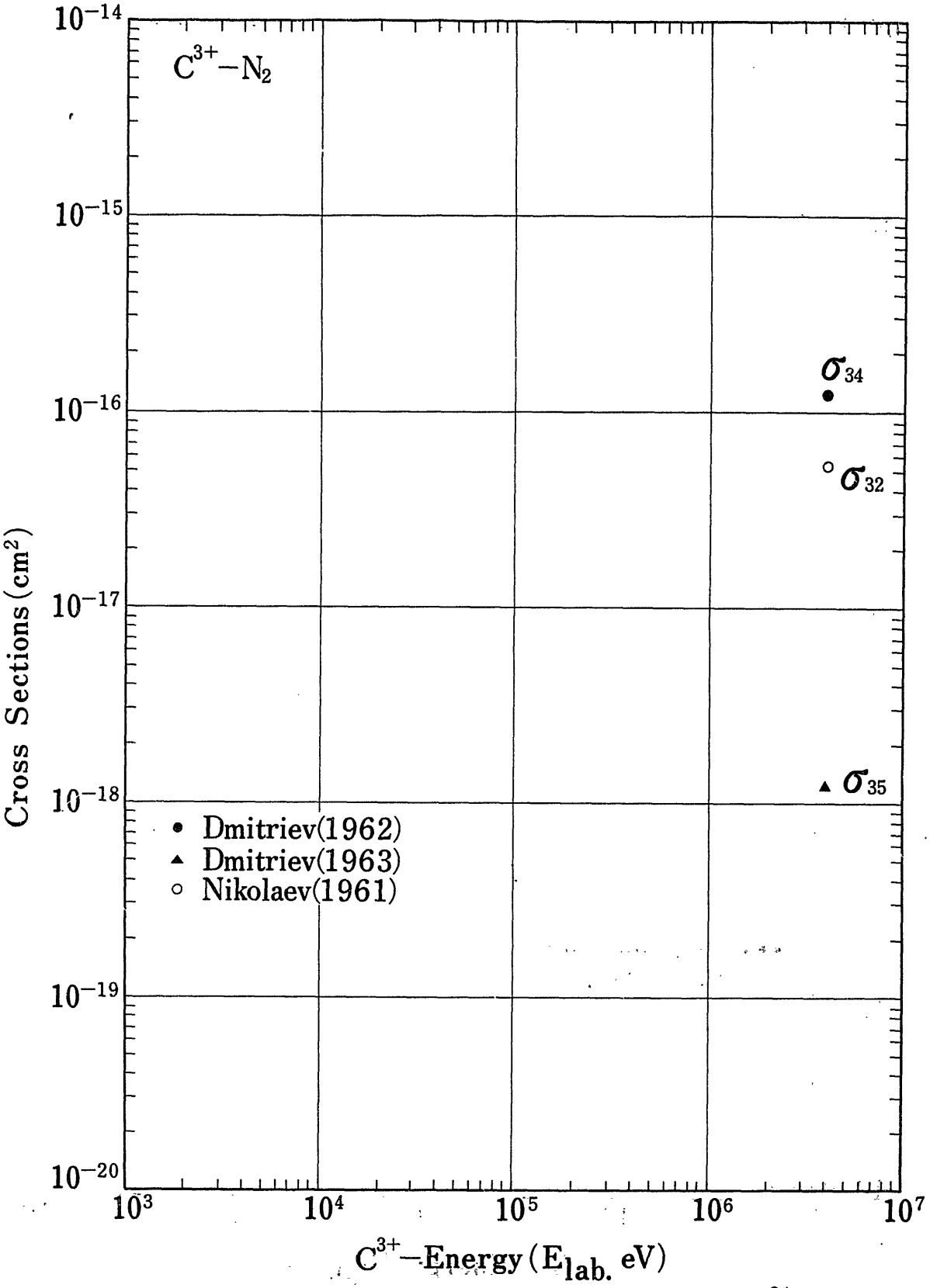


Fig.15 Charge Changing Cross Sections of C^{3+} in N_2

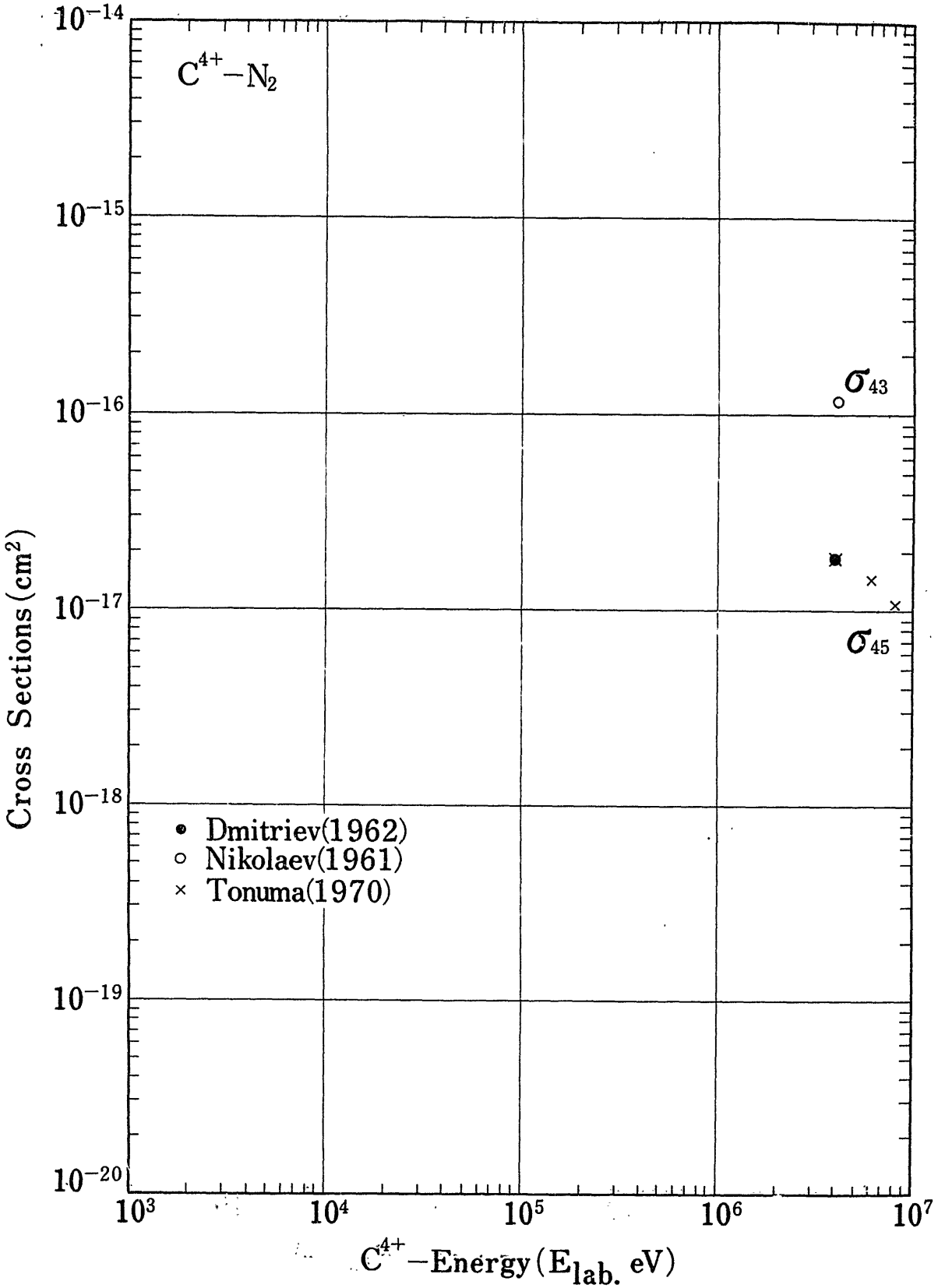


Fig. 16 Charge Changing Cross Sections of C^{4+} in N_2

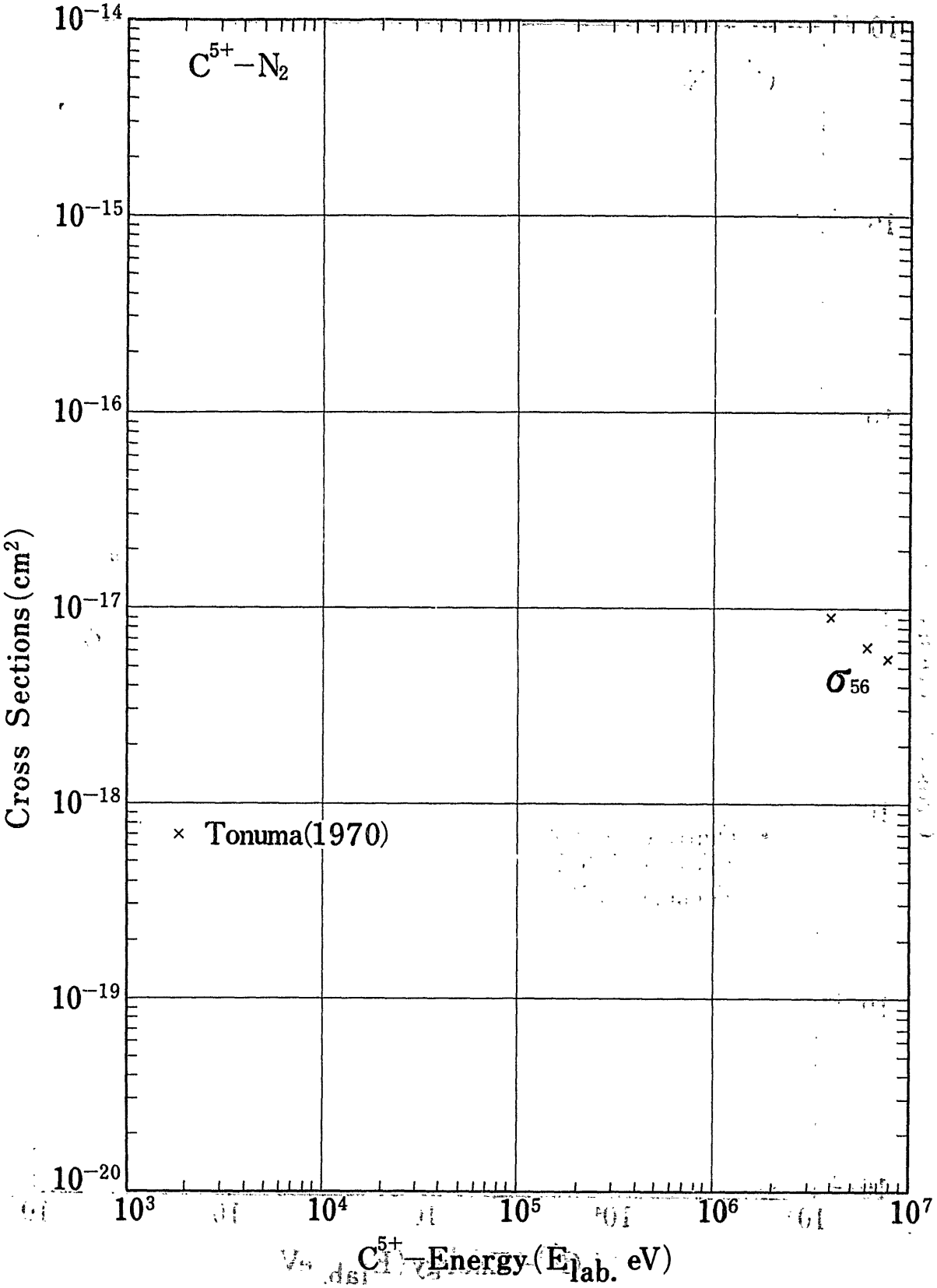


Fig.17 Charge-Changing Cross Sections of C^{5+} in N_2

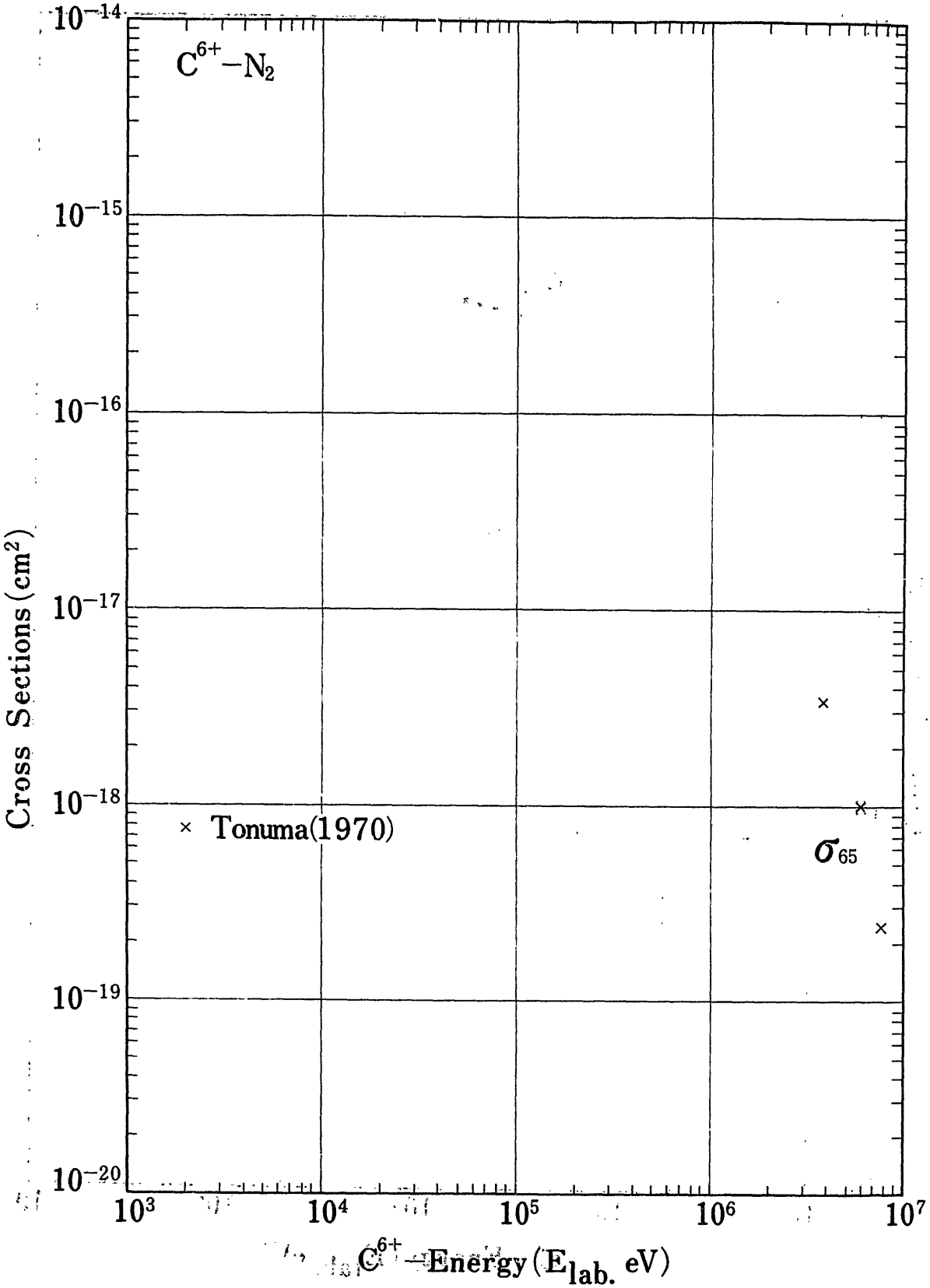


Fig.18 Charge Changing Cross Sections of C^{6+} in N_2

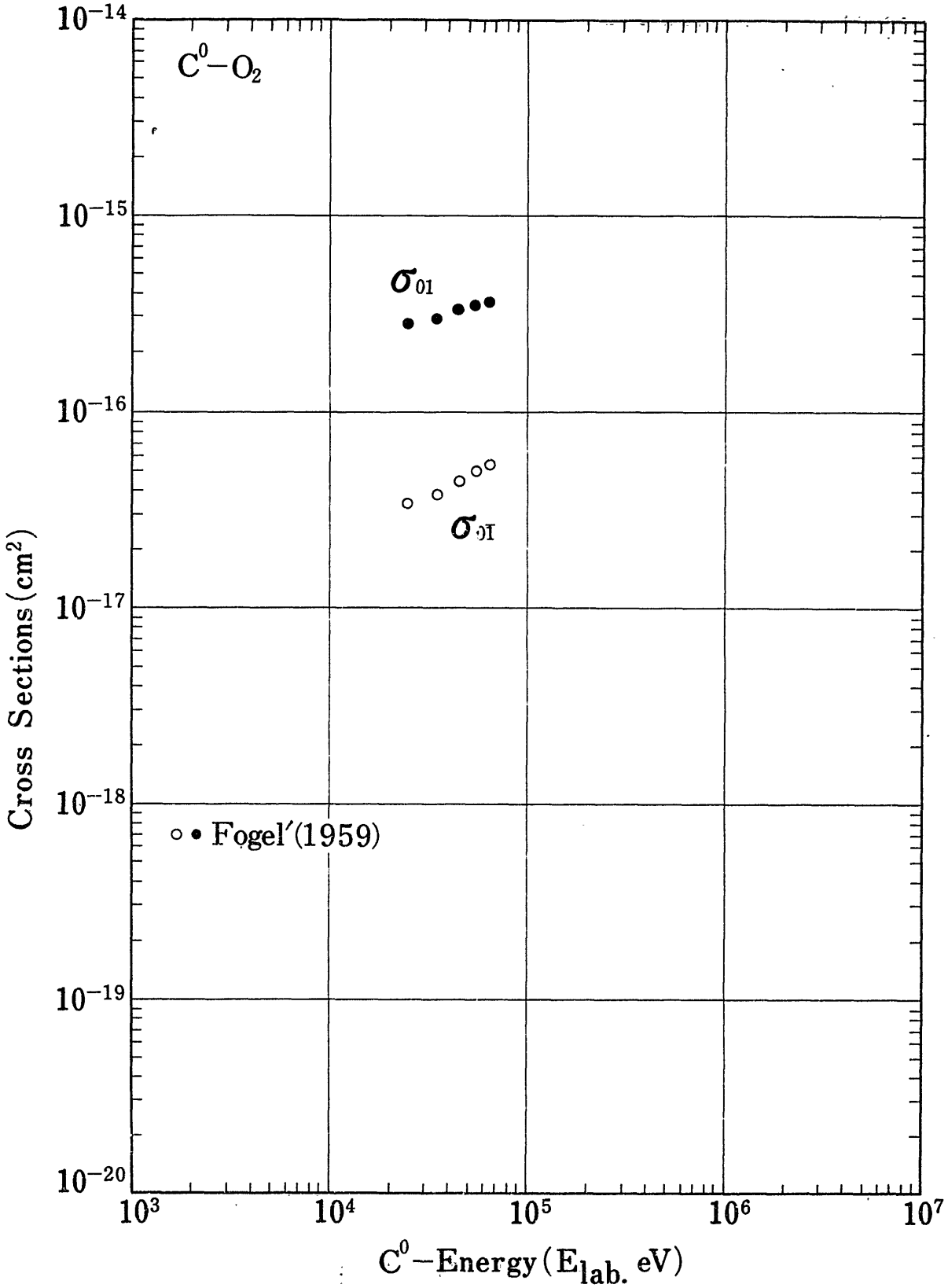


Fig.19 Charge Changing Cross Sections of C^0 in O_2

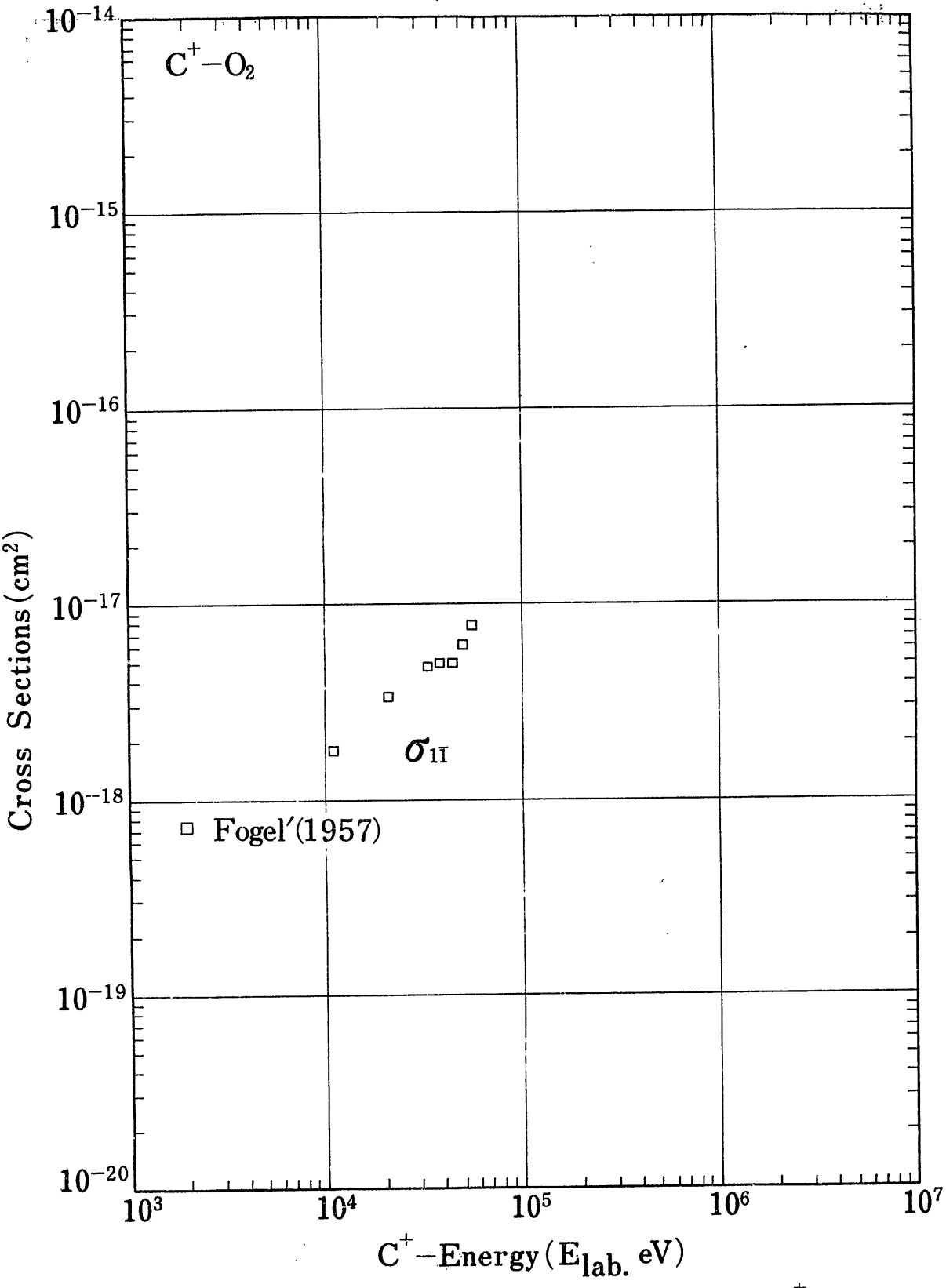


Fig.20 Charge Changing Cross Sections of C^+ in O_2

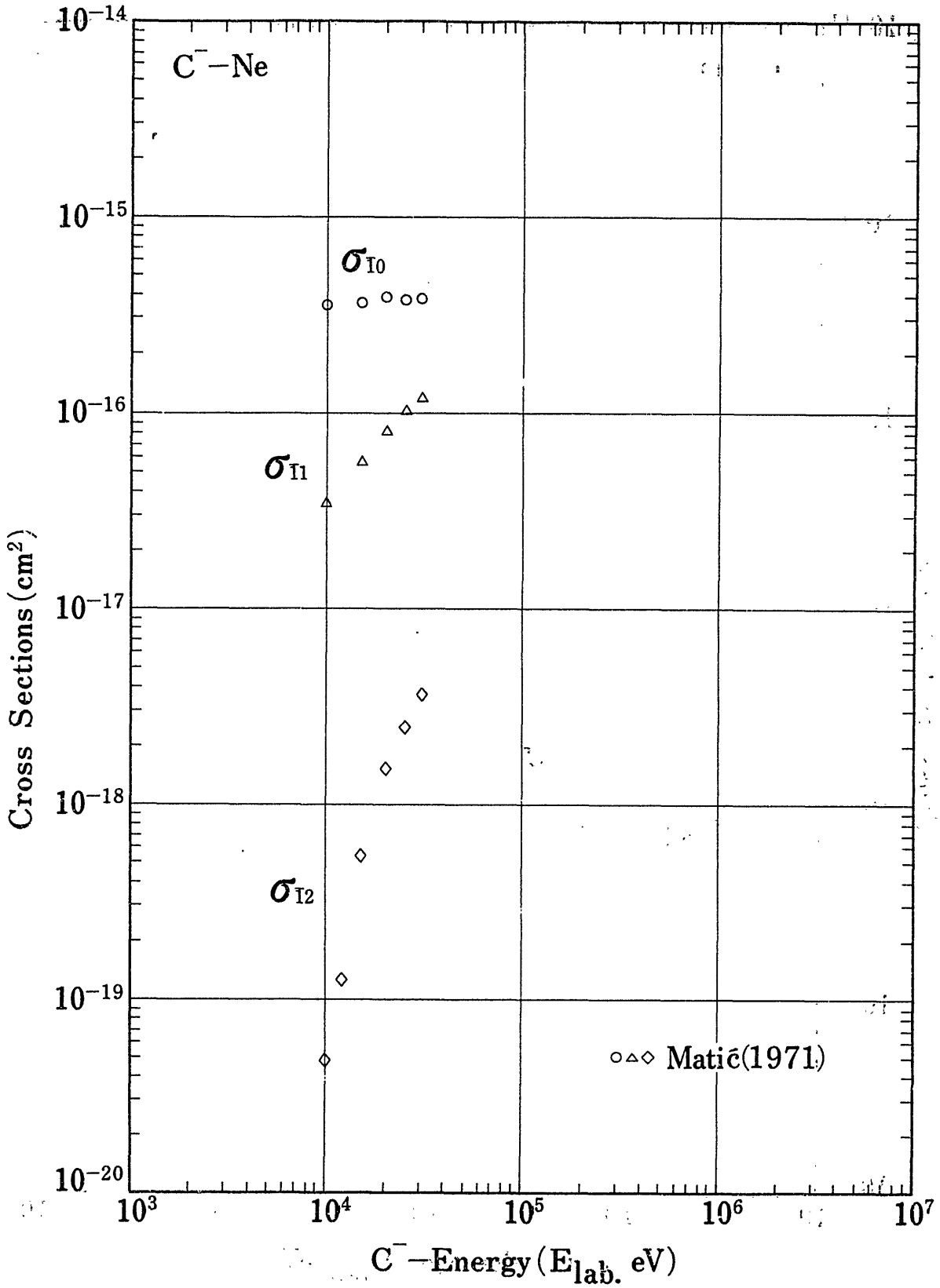


Fig.21 Charge Changing Cross Sections of C^- in Ne

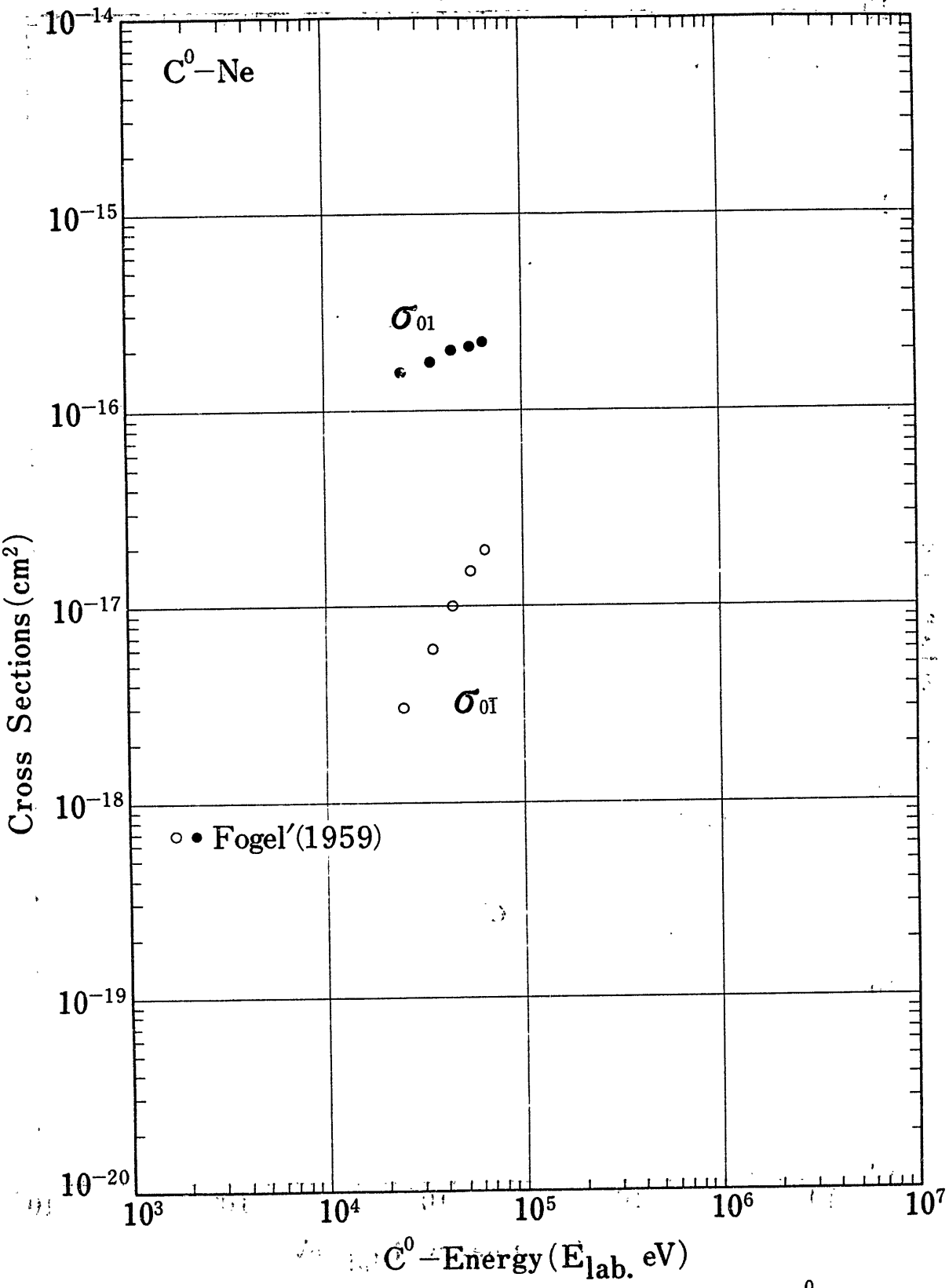


Fig.22 Charge Changing Cross Sections of C^0 in Ne

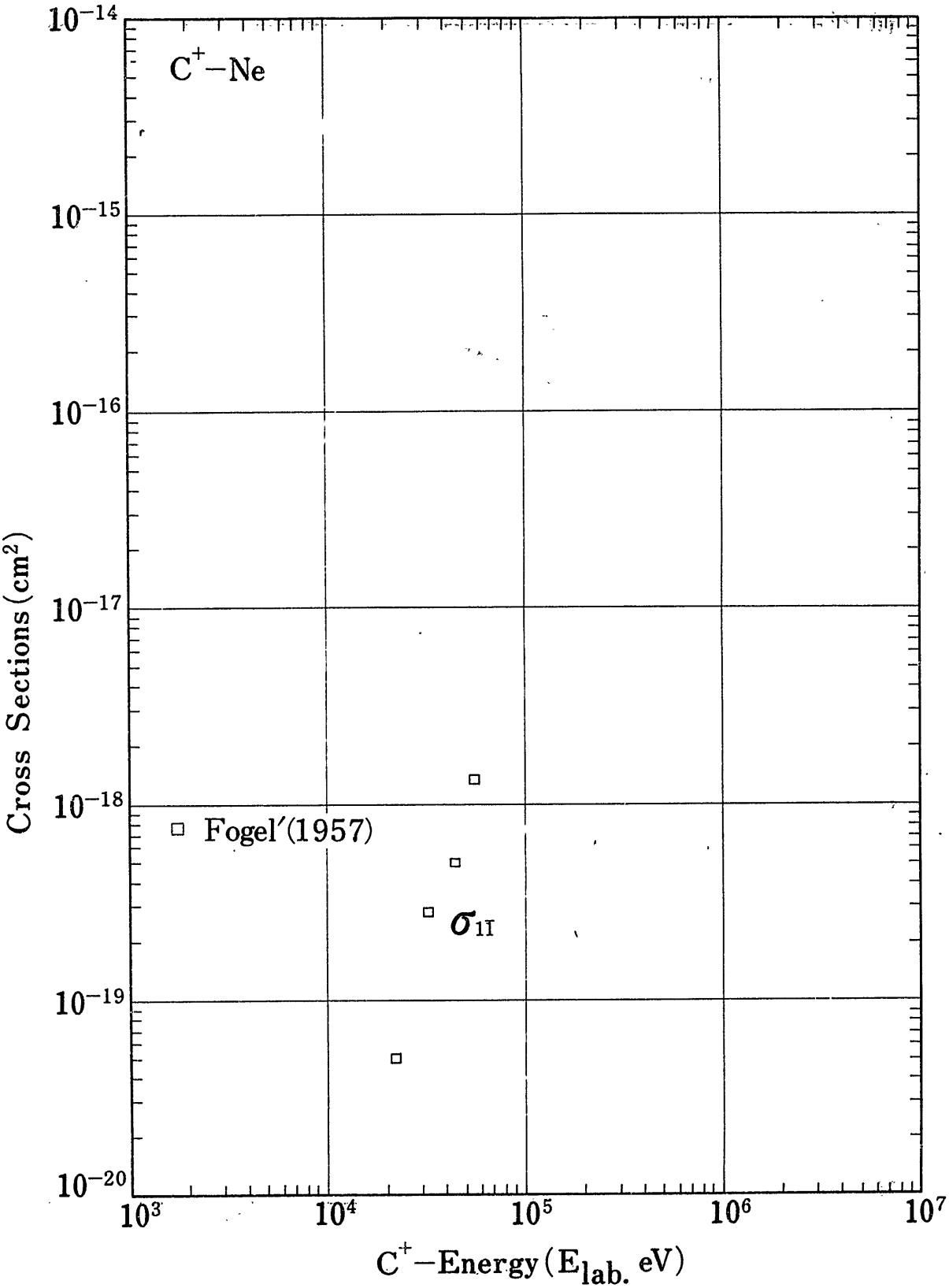


Fig.23 Charge Changing Cross Sections of C^+ in Ne

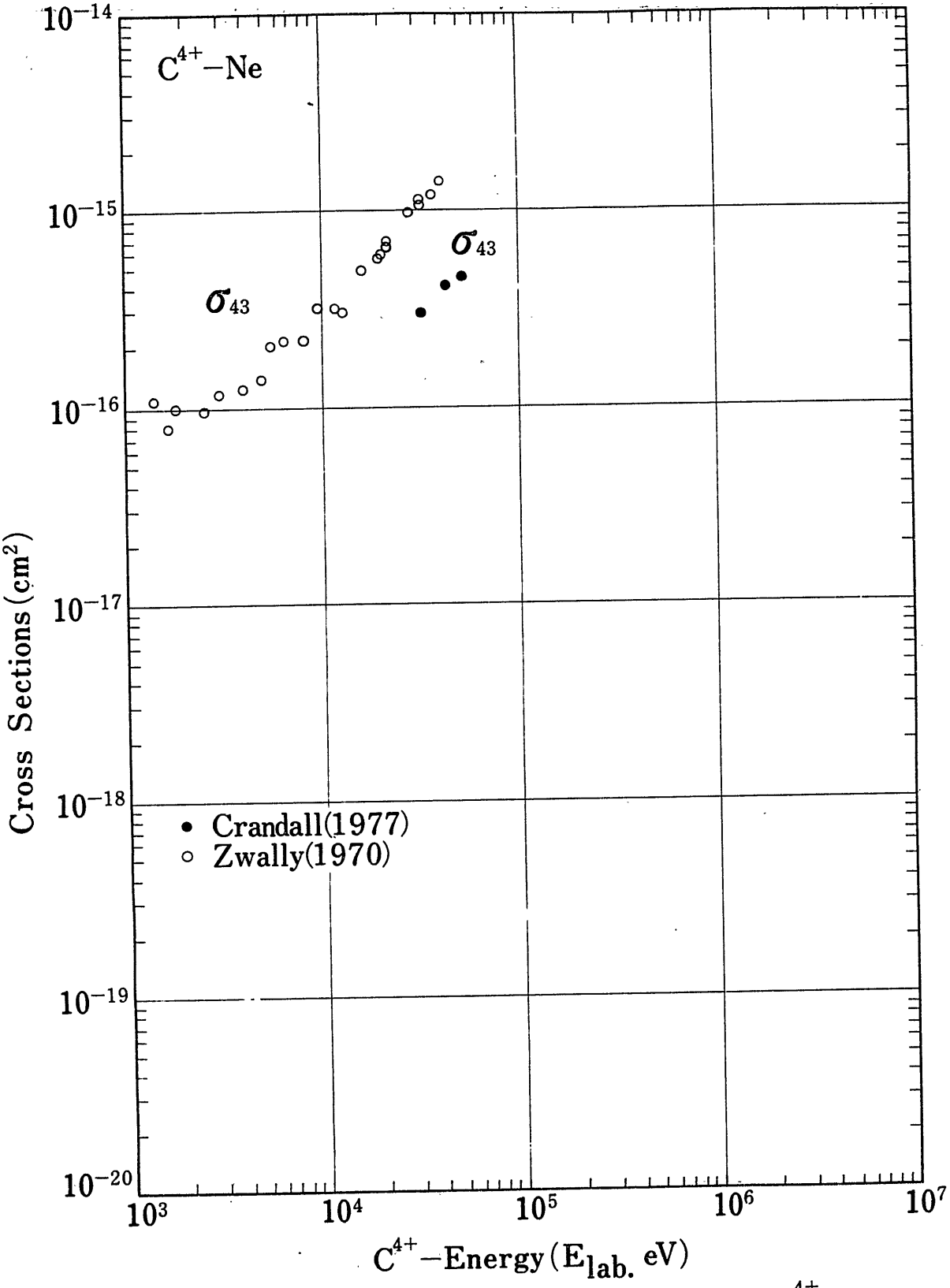


Fig.24 Charge Changing Cross Sections of C^{4+} in Ne

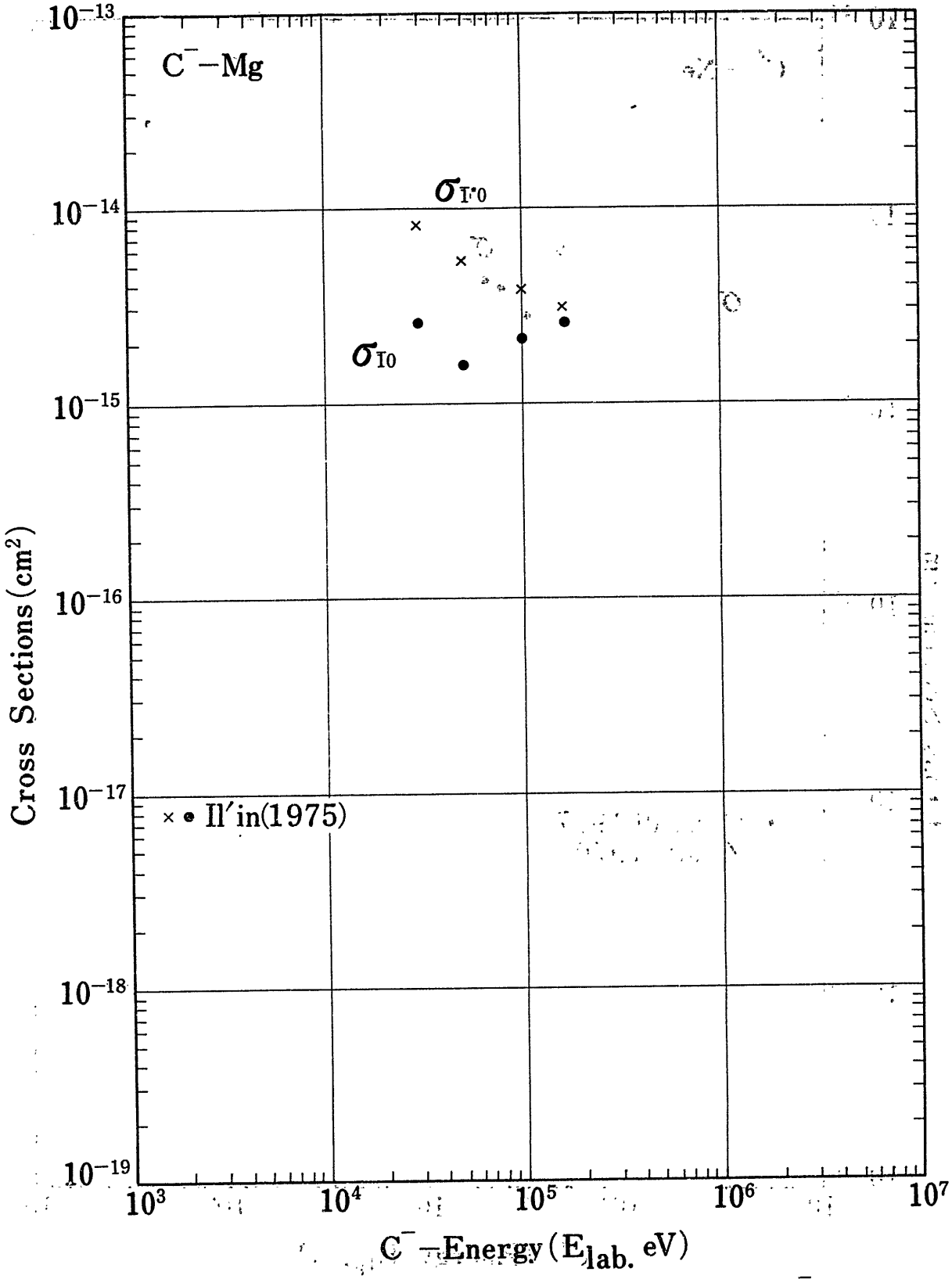


Fig.25 Charge Changing Cross Sections of C^- in Mg

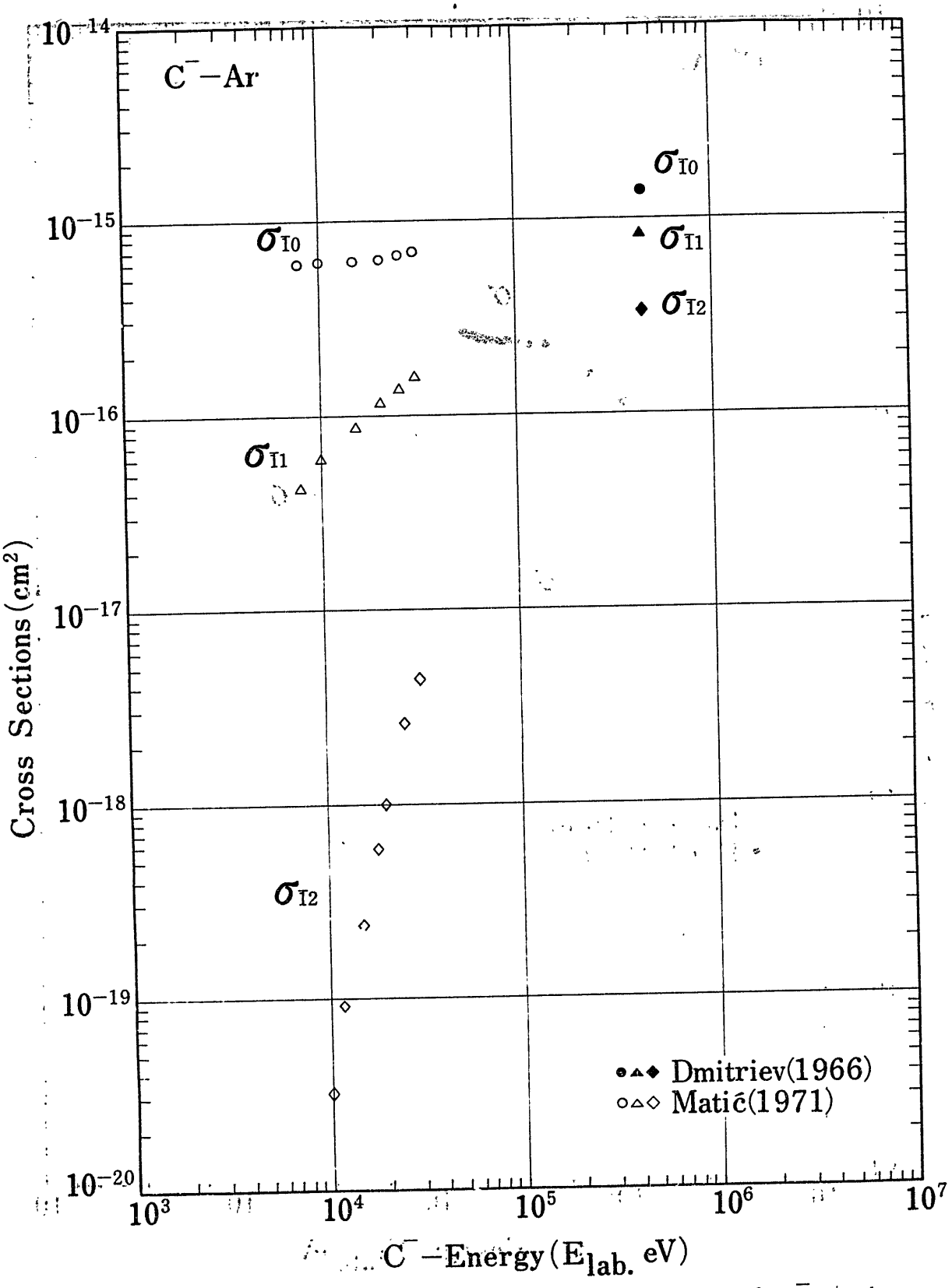


Fig.26 Charge Changing Cross Sections of C^- in Ar

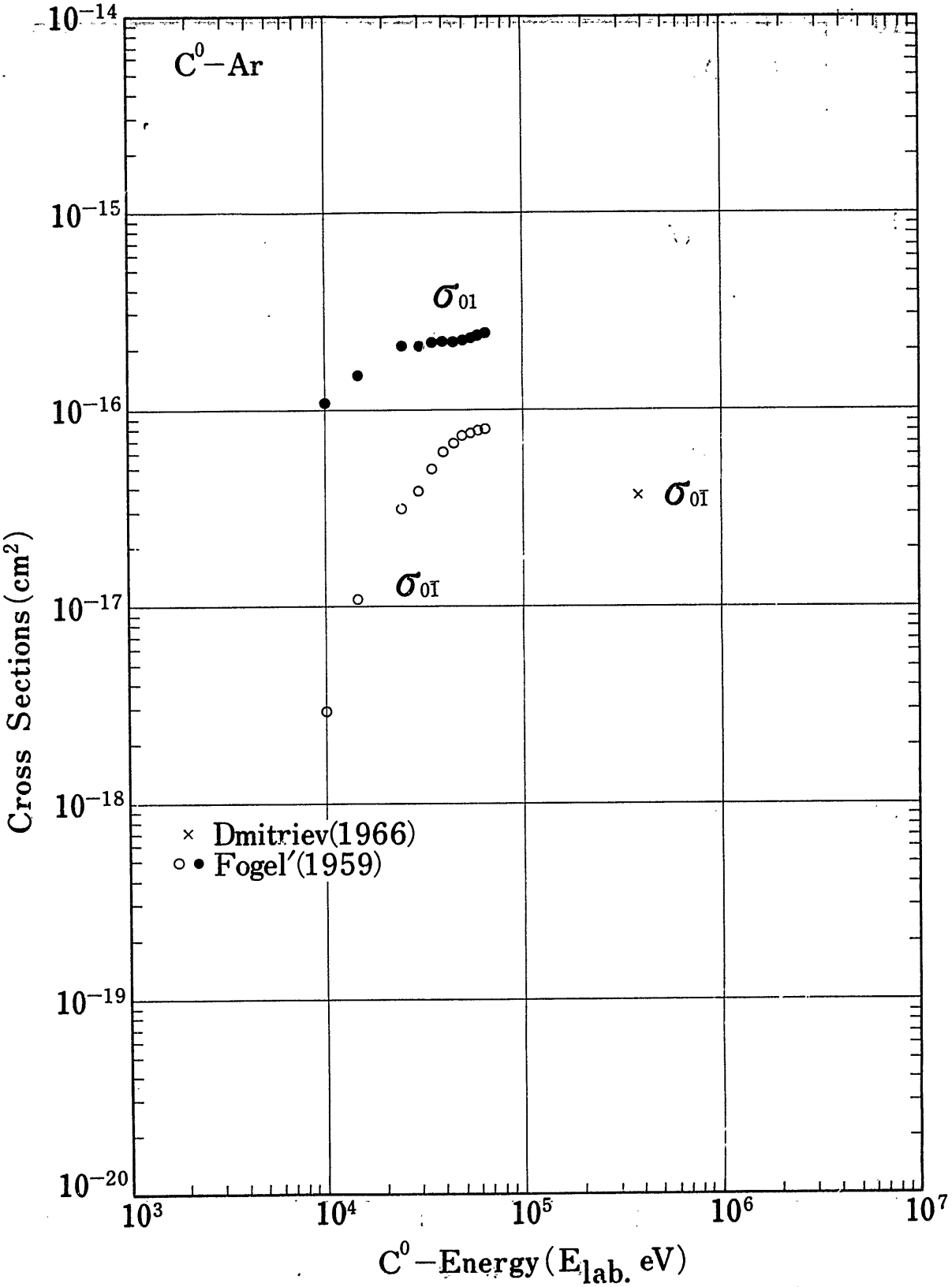


Fig.27 Charge Changing Cross Sections of C^0 in Ar

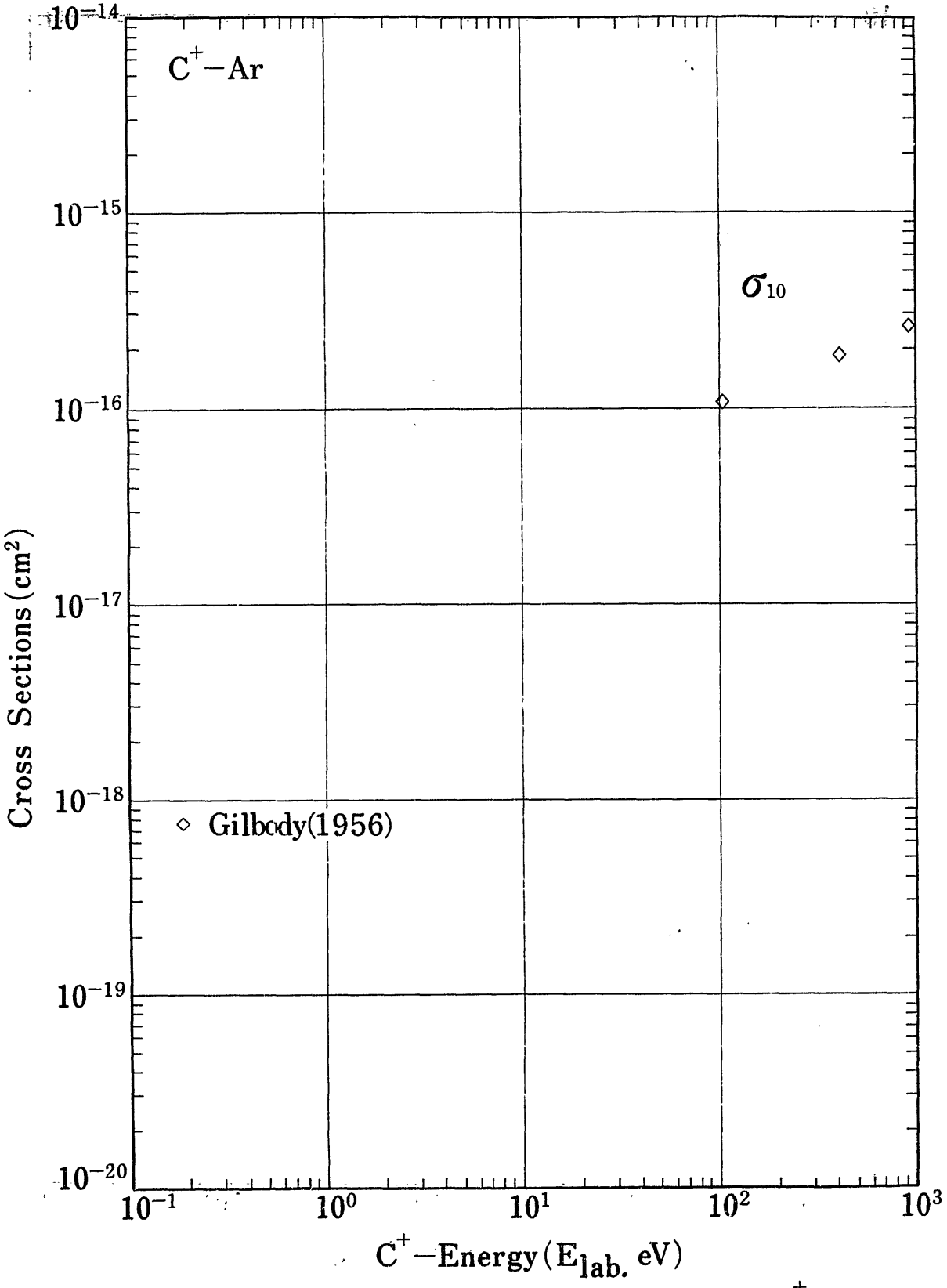


Fig. 28 −a Charge Changing Cross Sections of C^+ in Ar

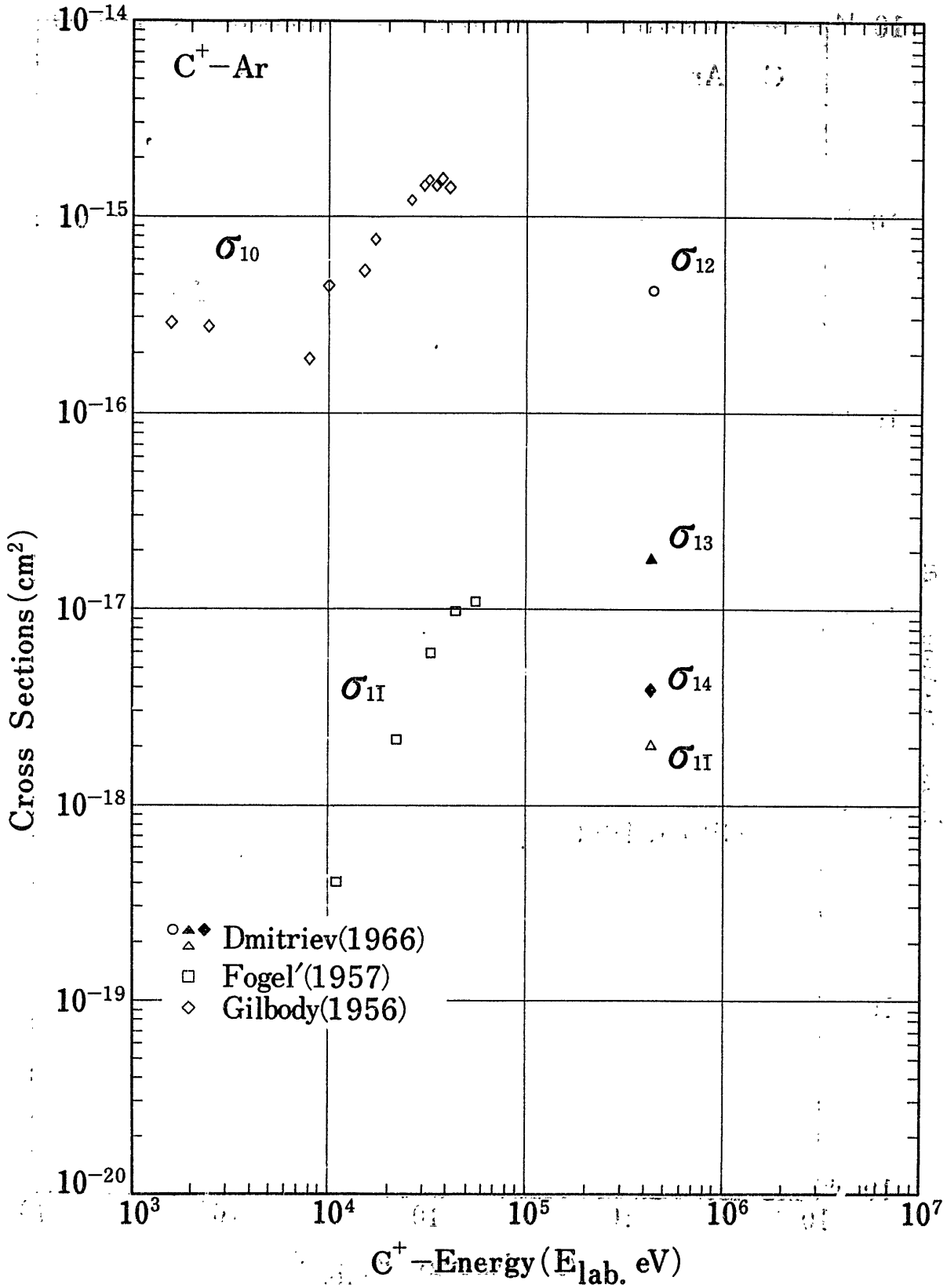


Fig.28−b Charge Changing Cross Sections of C^+ in Ar

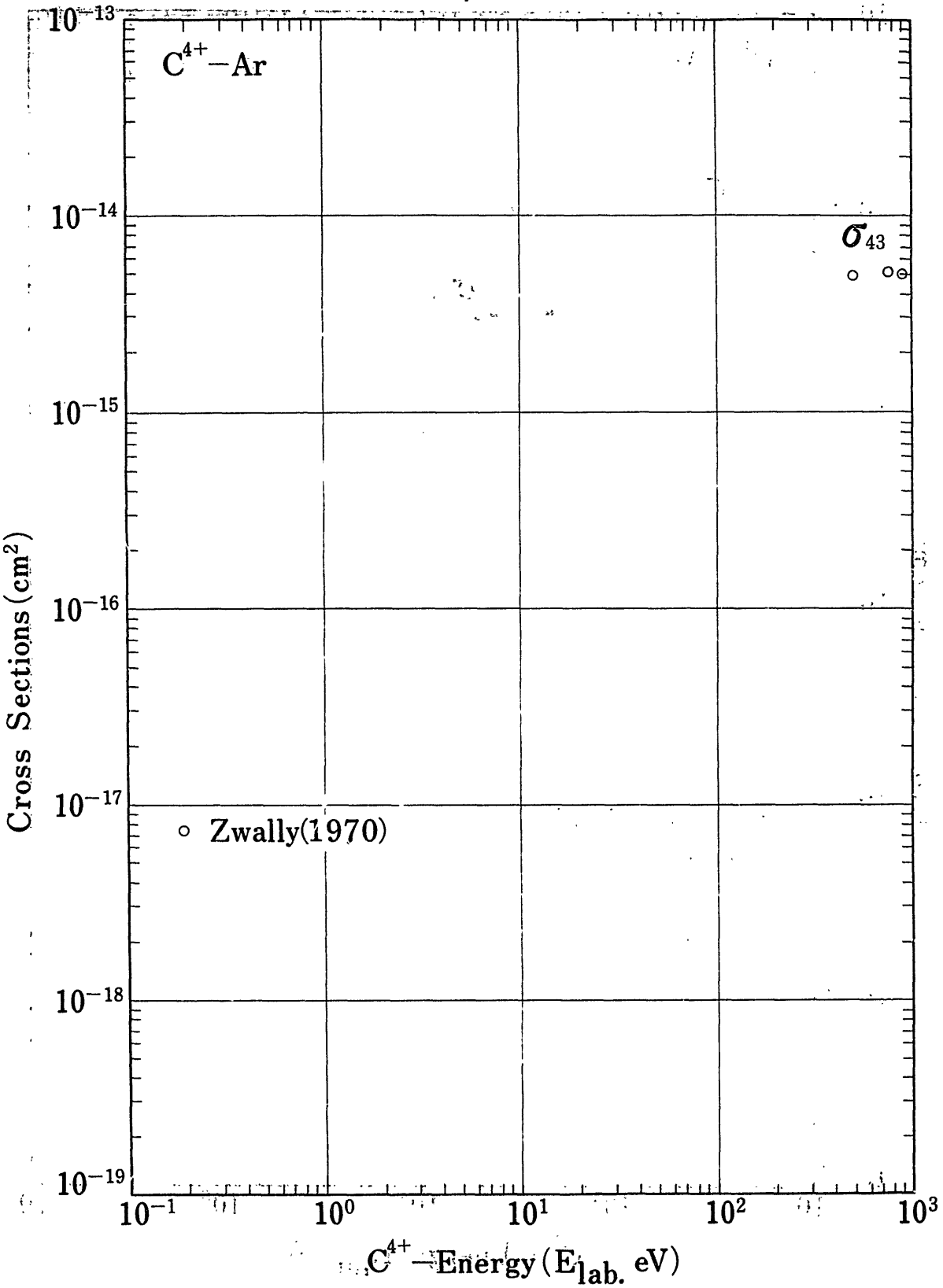


Fig.29—a Charge Changing Cross Sections of C^{4+} in Ar

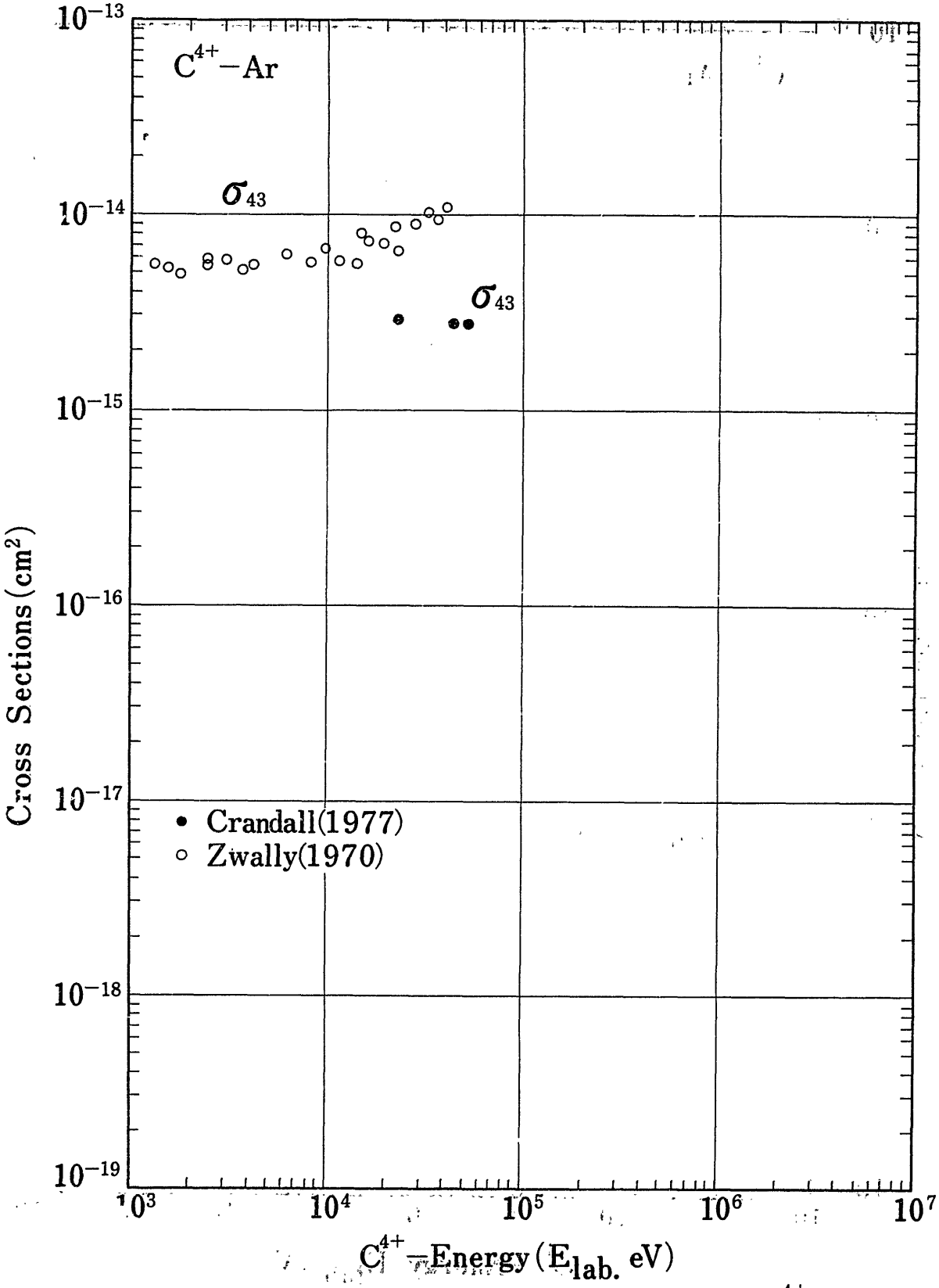


Fig.29−b Charge Changing Cross Sections of C^{4+} in Ar

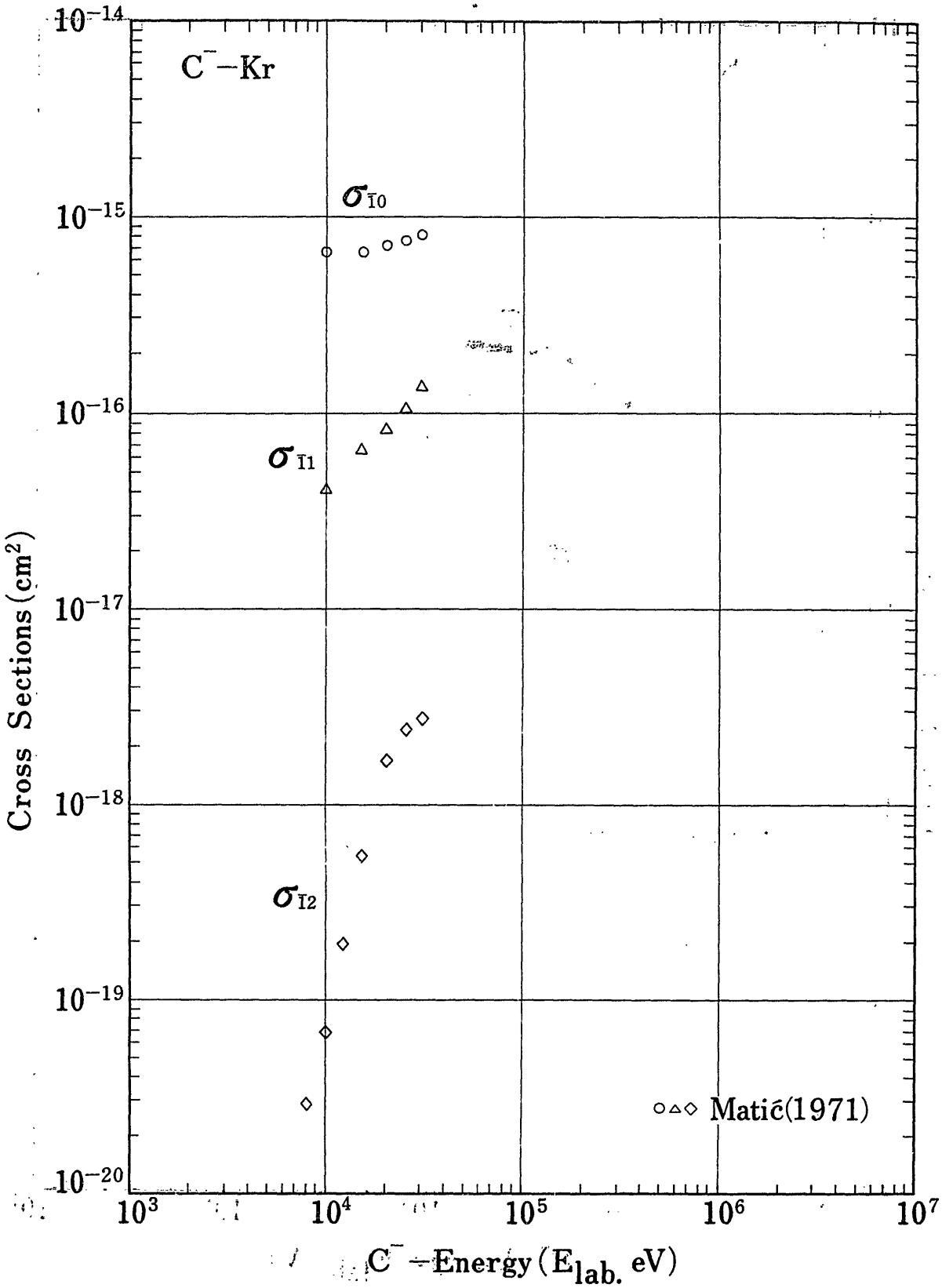


Fig. 30 Charge Changing Cross Sections of C^- in Kr

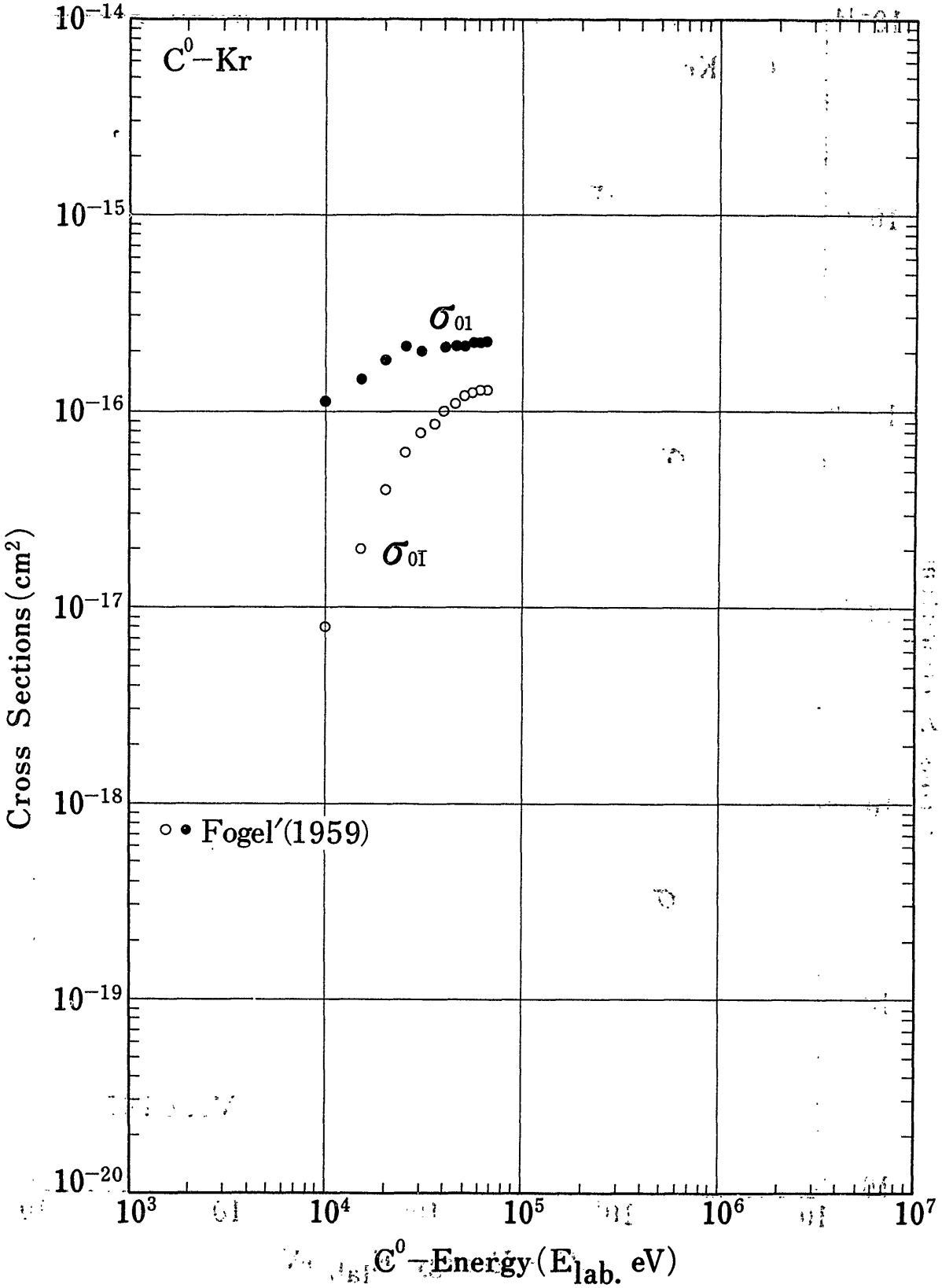


Fig. 31 Charge Changing Cross Sections of C^0 in Kr

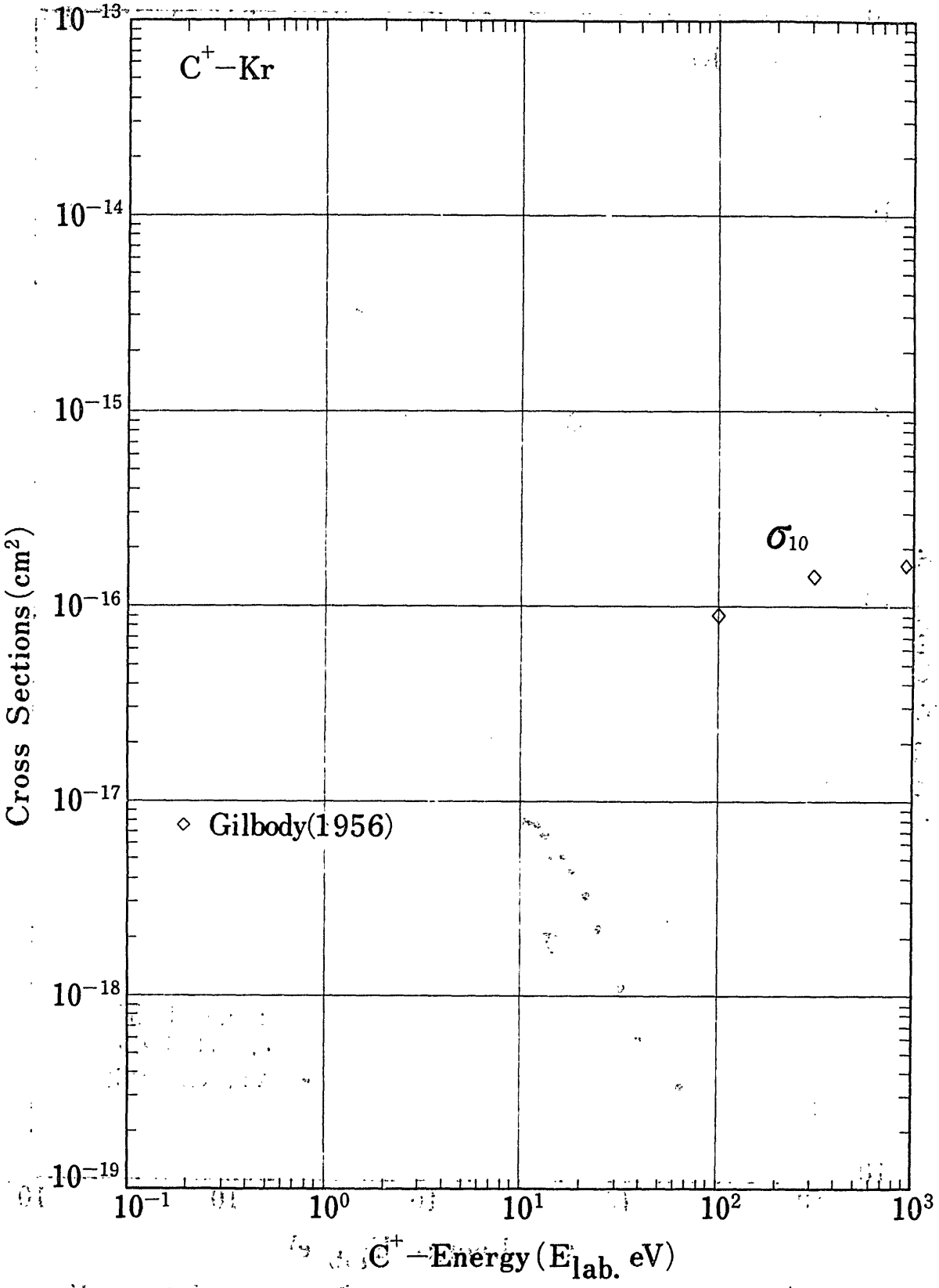


Fig.32–a Charge Changing Cross Sections of C^+ in Kr

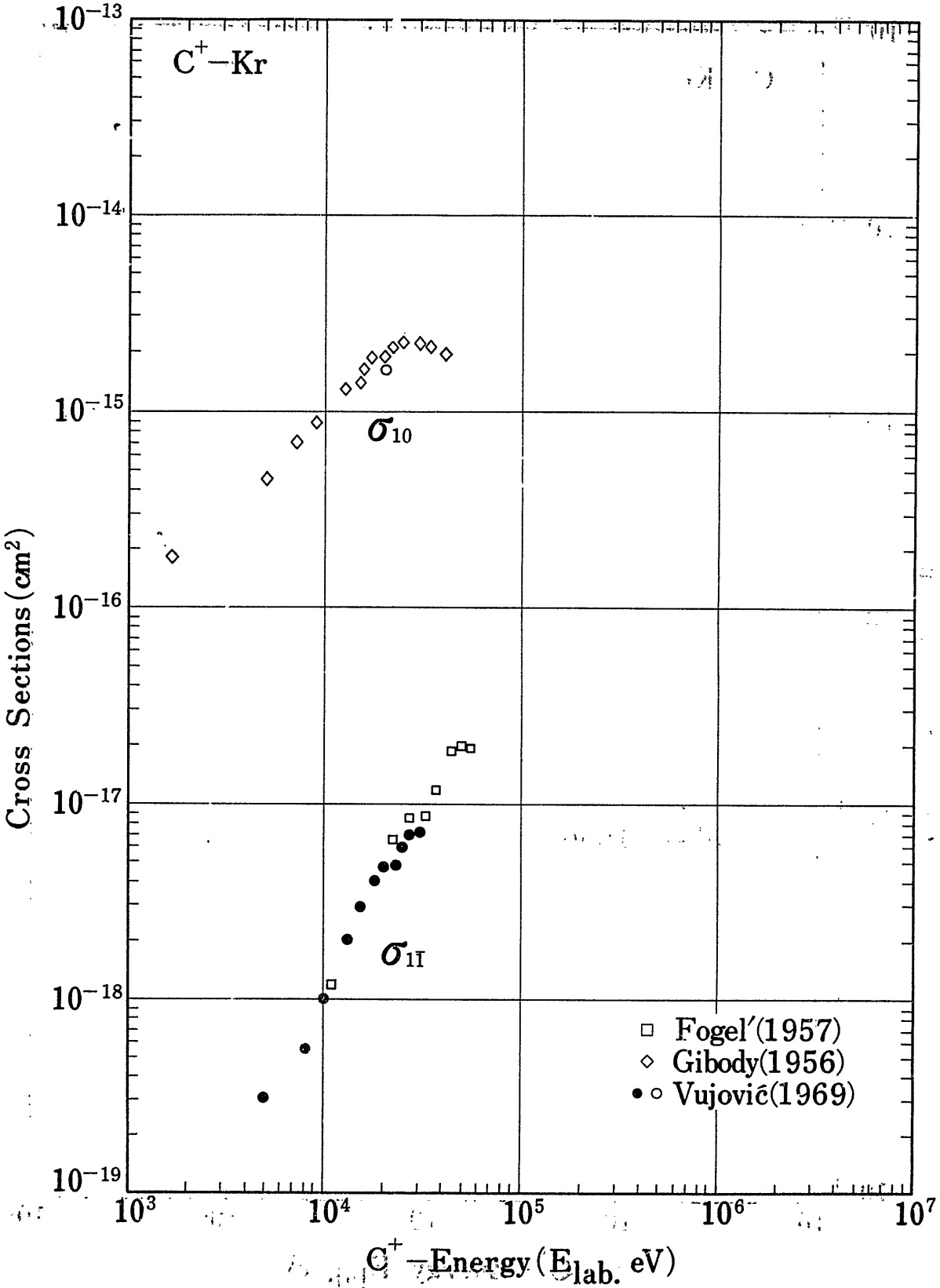


Fig.32—b Charge Changing Cross Sections of C^+ in Kr

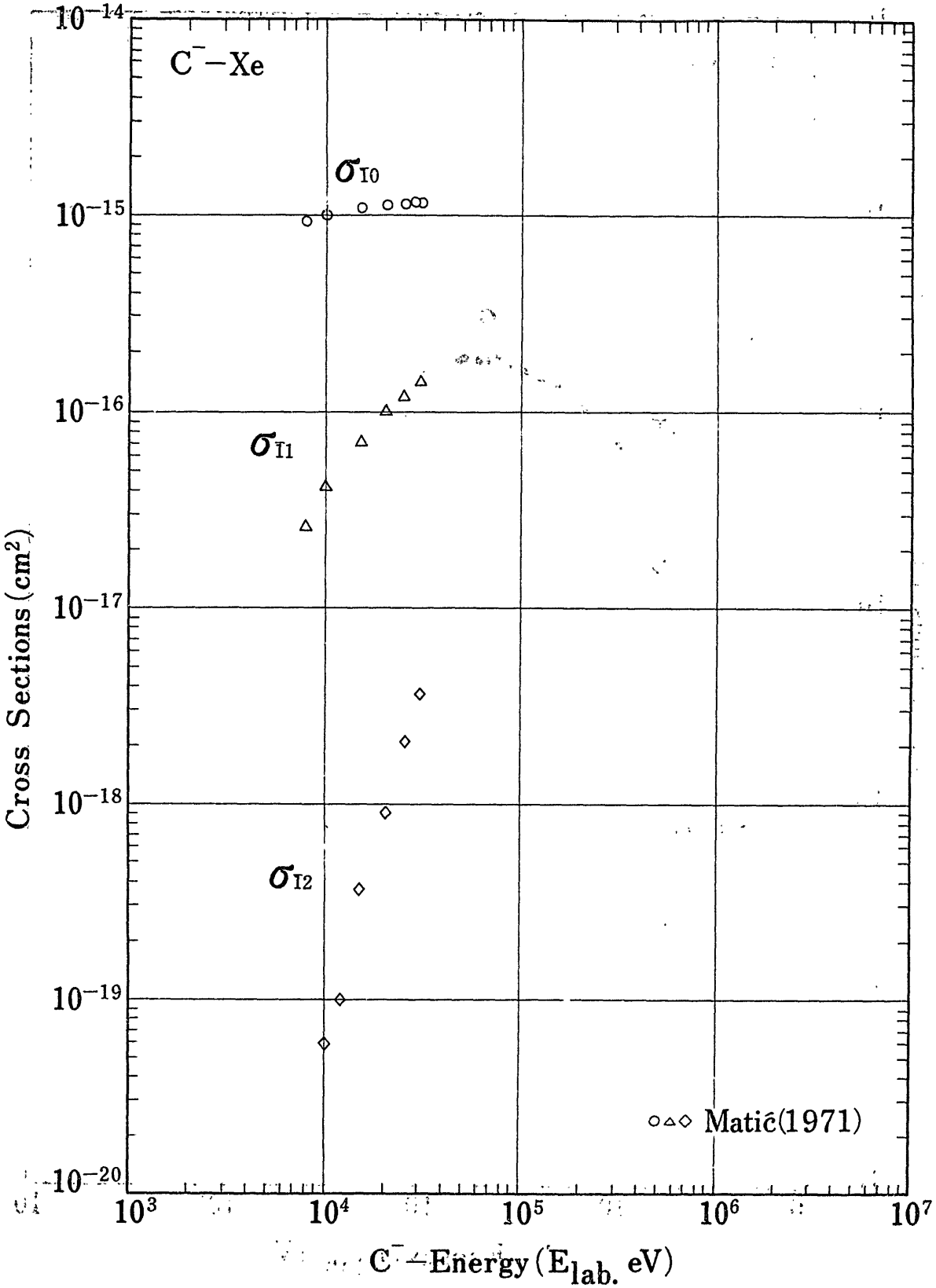


Fig.33 Charge Changing Cross Sections of C^- in Xe

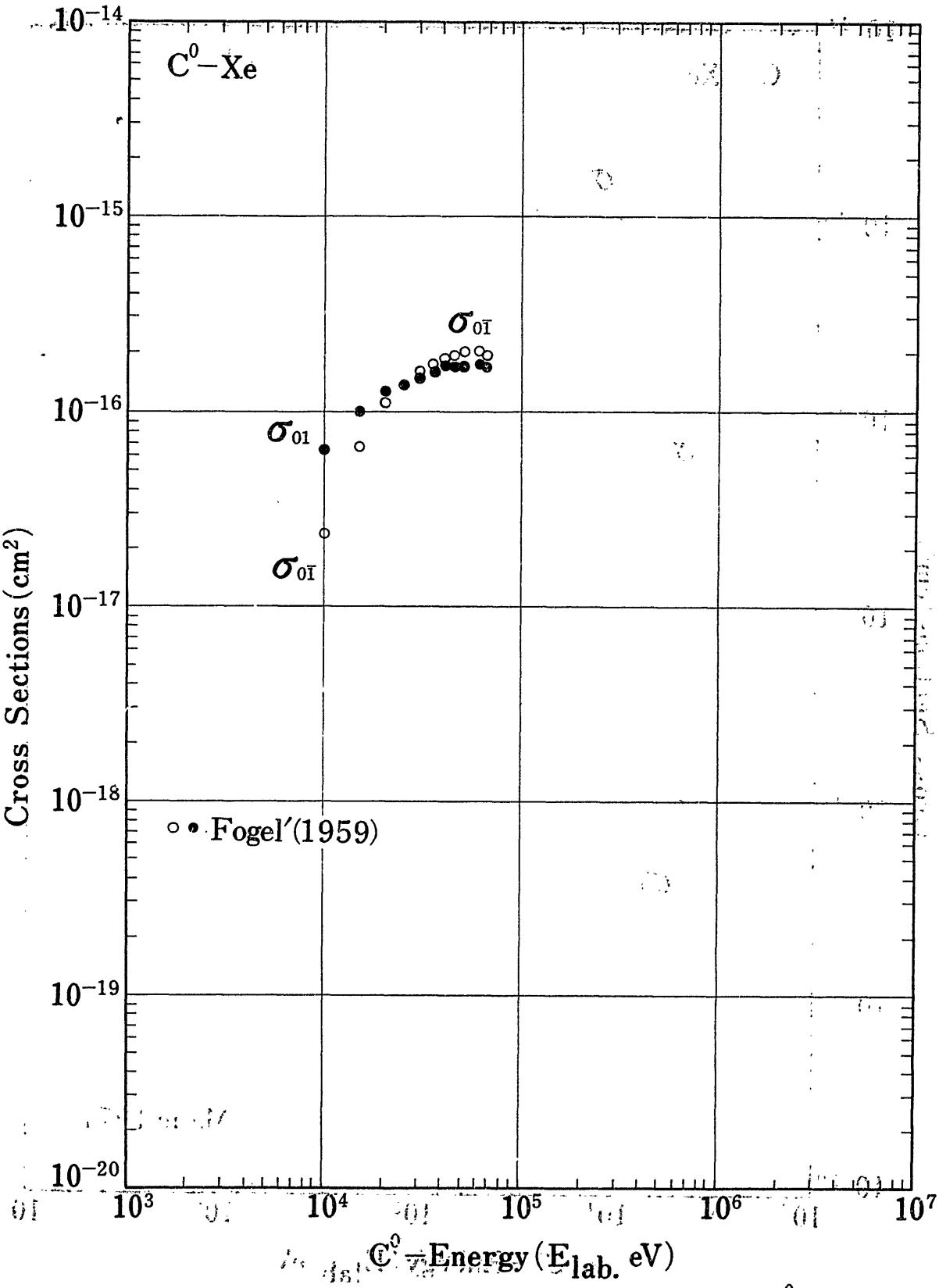


Fig. 34 Charge Changing Cross Sections of C^0 in Xe

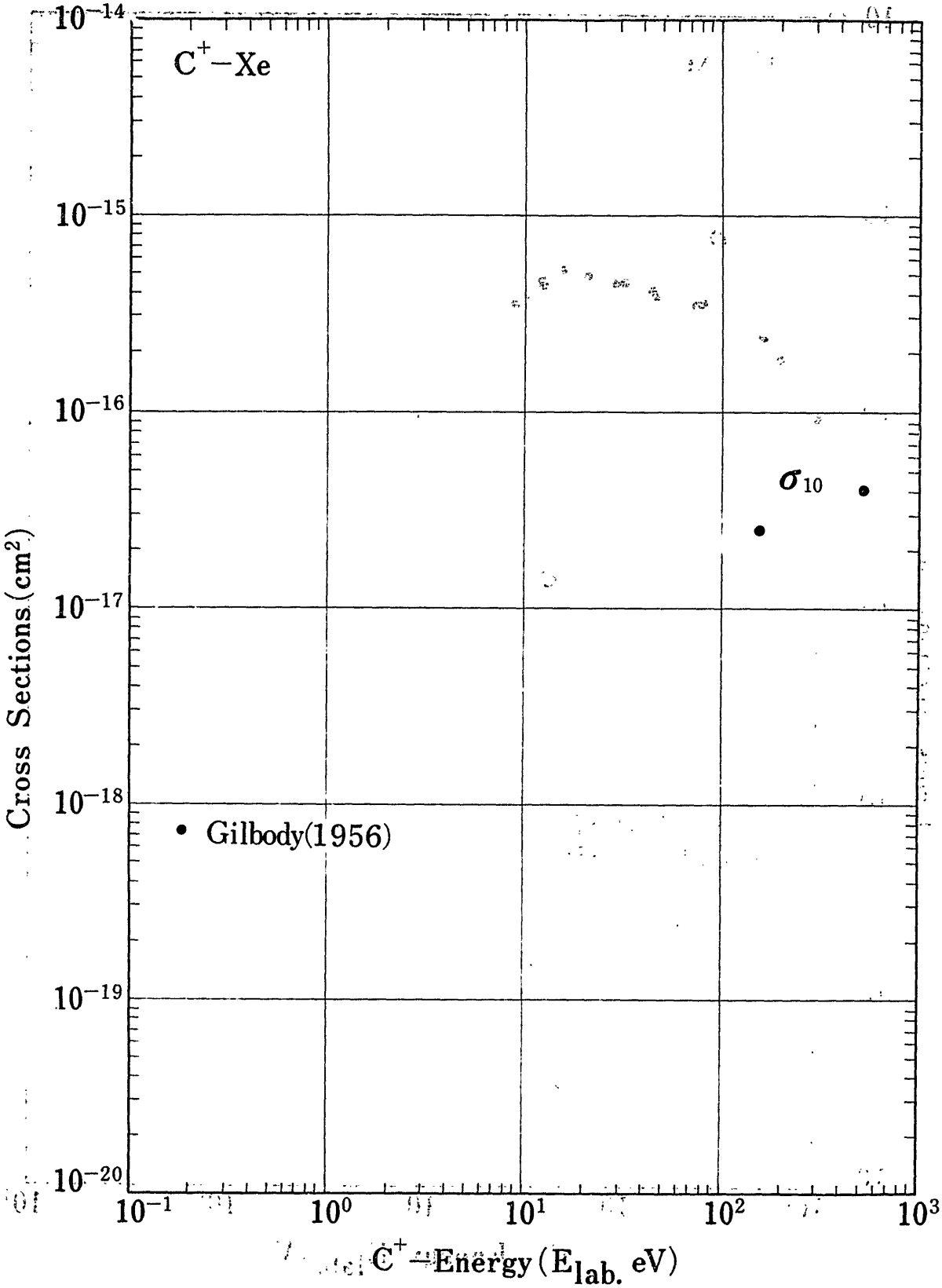


Fig. 35–a Charge Changing Cross Sections of C^+ in Xe

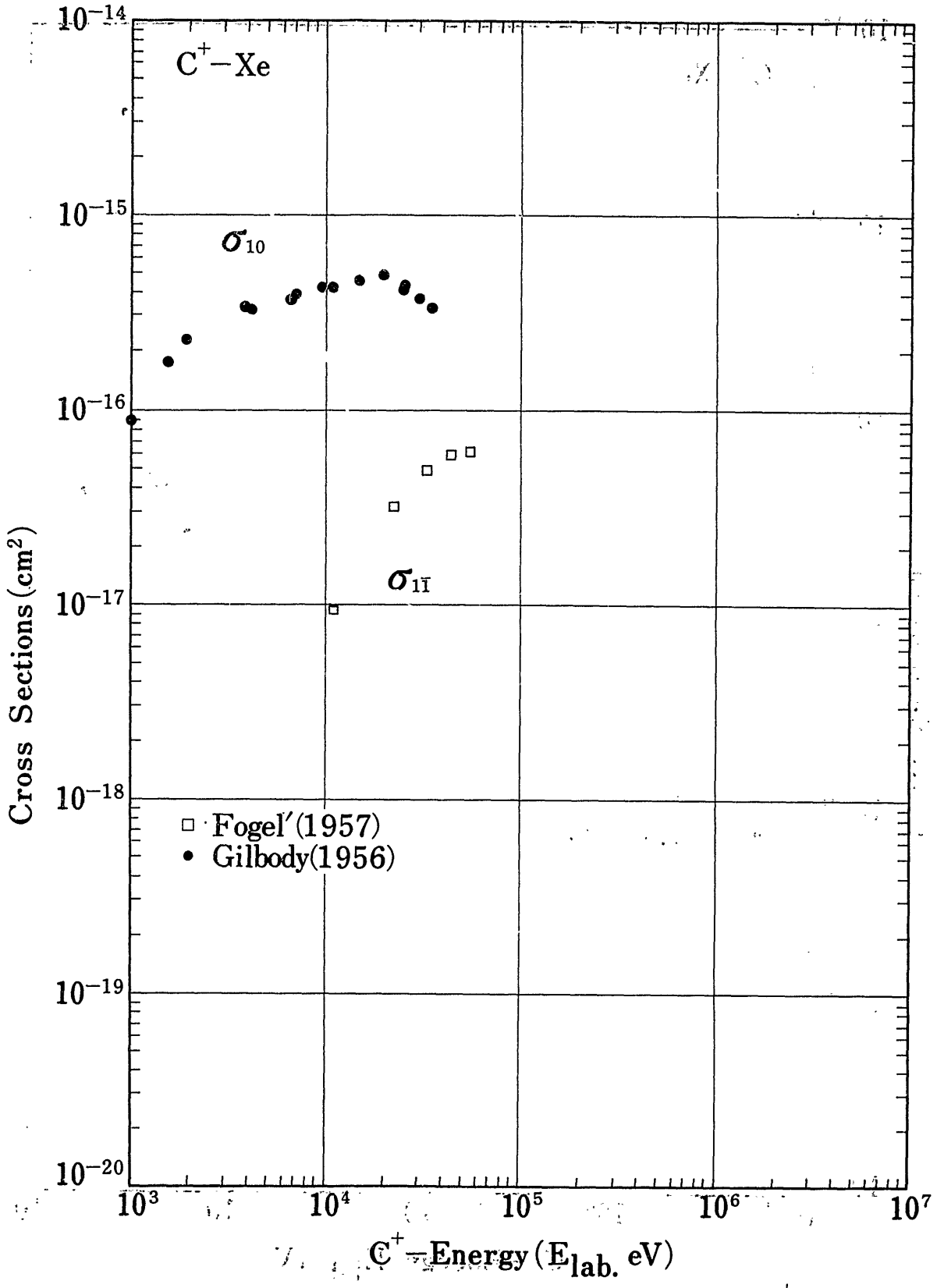


Fig. 35–b Charge Changing Cross Sections of C^+ in Xe

Charge Changing Cross Sections of Nitrogen Atoms and Ions, Z=7

I. Lists of Reference

II. Tables of Experimental Data

A) Electron Capture Cross Sections

B) Electron Loss Cross Sections

C) Cross Sections of Ionization, Slow ions Productions and Electron productions

III. Graphs of Charge Changing Cross Sections

I. References for Experimental Data of N (Z=7)

1. V.Aquilanti and G.G.Volpi, Ric. Sci. 36, 359 (1966)
2. V.A.Belyaev, B.G.Brezhnev and E.M.Erastov, Sov. Phys. JETP 27, 924 (1968)
3. R.T.Brackmann and W.L.Fite, AFWL-TR-68-96 (1968)
4. D.H.Crandall, Proc. 9th ICPEAC,Seattle (1975) p.190
5. D.H.Crandall, M.L.Mallory and D.C.Kocher, Phys. Rev. A 15, 61 (1977)
6. D.H.Crandall, Phys. Rev. A 16, 958 (1977)
7. F.J.de Heer, W.Huizenga and J.Kistemaker, Appl. Sci. Res. B 5, 337 (1955)
8. F.J.de Heer, W.Huizenga and J.Kistemaker, Physica. 23, 181 (1957)
9. I.S.Dmitriev, V.S.Nikolaev, L.N.Fateeva and Y.A.Teplova, Sov. Phys. JETP 15, 11 (1962)
10. I.S.Dmitriev, V.S.Nikolaev, L.N.Fateeva and Y.A.Teplova, Sov. Phys. 16, 259 (1963)
11. I.S.Dmitriev, V.S.Nikolaev, Ya.A.Teplova, B.M.Popov and L.I.Vinogradova, Sov. Phys. JETP 23, 832 (1966)
12. I.S.Dmitriev, V.S.Nikolaev, Ya.A.Teplova and B.A. Prigodin, Proc. 6th ICPEAC,Cambridge, (1969) p.460
13. I.S.Dmitriev, V.S.Nikolaev and Ya.A.Teplova, Proc. 7th ICPEAC,Amsterdam, (1971) p.510
14. I.S.Dmitriev, Ya.A.Teplova and V.S.Nikolaev, Sov. Phys. JETP 34, 723 (1972)
15. I.S.Dmitriev, V.S.Nikolaev, Yu.A.Tashaev and Ya.A. Teplova, Sov. Phys. JETP 40, 1017 (1975)
16. D.B.Dunking, F.C.Fehsenfeld, A.L.Schmeltekopf and E.E. Ferguson, J. Chem. Phys. 49, 1365 (1968)
17. N.V.Fedorenko, Zh. Tech. Fiz. 24, 769 (1954)
18. F.C.Fehsenfeld, E.E.Ferguson and A.L.Schmeltekopf, J. Chem. Phys. 44, 4537 (1966)

19. E.E.Ferguson, F.C.Fehsenferd, P.D.Golden and A.L. Schmeltekopf, J. Geophys. Res. 70, 4323 (1965)

20. W.L.Fite, J.A.Rutherford, W.R.Snow and V.A.Van Lint, Discussions Faraday Soc. 33, 264 (1962)

21. W.L.Fite, J.D.Garcia, E.Gerjouy and J.A.Pedan, AFWL-TR-69-26 (1969)

22. I.P.Flaks and G.N.Ogurtsov, Sov. Phys. Tech. Phys. 8, 560 (1963)

23. Ya.M.Fogel', R.V.Mitin and A.G.Koval', Sov. Phys. JETP 4, 359 (1957)

24. Ya.M.Fogel', L.I.Krupnik, A.G.Koval' and R.P. Slabospitskii, Sov. Phys. Tech. Phys. 2, 902 (1957)

25. Ya.M.Fogel', V.A.Ankudinov, D.V.Pilipenko and N.V. Topolia, Sov. Phys. JETP 7, 400 (1958)

26. H.B.Gilbody and J.B.Hasted, Proc. Roy. Soc. A239, 334 (1956)

27. P.D.Goldan, A.L.Schmeltekopf, F.C.Fehsenfeld, H.I. Schiff and E.E.Ferguson, J. Chem. Phys. 44, 4095 (1966)

28. J.B.Hasted, Proc. Roy. Soc. A205, 421 (1951)

29. J.B.Hasted and R.A.Smith, Proc. Roy. Soc. A235, 349 (1956)

30. J.B.Hasted, S.M.Iqbal and M.M.Yousaf, Proc. 7th ICPEAC, Amsterdam, (1971) p.126

31. J.B.Hasted, S.M.Iqbal and M.M.Yousaf, J. Phys. B 4, 343 (1971)

32. R.Hippler and K.H.Schartner, J. Phys. B 8, 2528 (1975)

33. B.Hird and H.C.Suk, Phys. Rev. A 14, 928 (1976)

34. R.N.Il'in and E.S.Solov'ev, Sov. Phys. Tech. Phys. 6, 491 (1961)

35. R.Johnsen, H.L.Brown and M.A.Biondi, J. Chem. Phys. 52, 5080 (1970)

36. Y.Kaneko, N.Kobayashi and I.Kanomata, Mass Spectroscopy 18, 920 (1970)

37. E.J.Knystantas, Q.C.Kessel, R.DelBoca and H.C.Hayden, Phys. Rev. A 1, 825 (1970)

38. M.I.Korsunsky, L.I.Pivovar, A.M.Markus and Kh.L. Leviant, Akad. Nauk. SSR, "Doklady" 103, 399 (1955)

39. R.G.Kosmider and J.B.Hasted, J. Phys. B 8, 273 (1975)

40. Z.Z.Latypov, N.V.Fedorenko, I.P.Flaks and A.A. Shaporenko, Sov. Phys. JETP 28, 439 (1969)

41. H.H.Lo and W.L.Fite, Atomic Data 1, 305 (1970)

42. H.H.Lo, L.Kurzweg, R.T.Brackmann and W.L.Fite, Phys. Rev. A 4, 1462 (1971)

43. W.B.Maier II , J. Chem. Phys. 55, 2307 (1971)

44. J.W.McGowan and L.Kerwin, Canad. J. Phys. 45, 1451 (1967)

45. F.W.Meyer, C.J.Anderson and L.W.Anderson, Phys. Rev. A 15, 455 (1977)

46. V.S.Nikolaev, L.N.Fateeva, I.S.Dmitriev and Ya.A. Teplova, Sov. Phys. JETP 6, 239 (1957)

47. V.S.Nikolaev, L.N.Fateeva, I.S.Dmitriev and Ya.A. Teplova, Sov. Phys. JETP 13, 695 (1961)

48. V.S.Nikolaev, L.N.Fateeva, I.S.Dmitriev and Ya.A. Teplova, Sov. Phys. JETP 14, 67 (1962)

49. J.H.Ormrod and W.L.Michel, Canad. J. Phys. 49, 606 (1971)

50. R.A.Phaneuf, F.W.Meyer, R.H.McKnight, R.E.Olson and A.Salop, J. Phys. B 10, L425 (1977)

51. L.I.Pivovar, M.T.Novikov and A.S.Dolgov, Sov. Phys. JETP 23, 357 (1966)

52. R.F.Potter, J. Chem. Phys. 22, 974 (1954)

53. H.L.Reynolds, L.D.Wyly and A.Zucker, Phys. Rev. 98, 1825 (1955)

54. J.A.Rutherford, R.F.Mathis, B.R.Turner and D.A.Vroom, J. Chem. Phys. 55, 3785 (1971)

55. J.A.Rutherford, R.F.Mathis, B.R.Turner and D.A.Vroom, J. Chem. 56, 4654 (1972)

56. J.A.Rutherford and D.A.Vroom, J. Chem. Phys. 57, 3087 (1972)

57. J.A.Rutherford and D.A.Vroom, J. Chem. Phys, 57, 309 (1972)

58. J.A.Rutherford and D.A.Vroom, Proc. 8th ICPEAC, Beograd, (1973) p.807

59. J.A.Rutherford and D.A.Vroom, J. Chem. Phys. 62, 1460 (1975)

60. E.S.Solov'ev, R.N.Il'in, V.A.Oparin and I.T.Serenkov, Sov. Phys. JETP Lett. 10, 190 (1969)

61. R.F.Stebbings, W.L.Fite and D.G.Hummer, J. Chem. Phys. 33, 1226 (1960)

62. R.F.Stebbings, A.C.H.Smith and H.B.Gilbody, J. Chem. Phys. 38, 2280 (1963)

63. Ya.A.Teplova, V.S.Nikolaev, I.S.Dmitriev and Yu.A. Tashaev, Proc. 9th ICPEAC, Seattle, (1975) p.187

64. T.Tonuma, Y.Miyazawa, T.Karasawa and I.Kohno, Japan J. Appl. Phys. 9, 1306 (1970)

65. B.R.Turner and J.A.Rutherford, J. Geophys. Res. 73, 6751 (1968)

66. M.Vujovic, M.Matic, B.Cobic and P.H.Hvelplund, J. Phys. B 10, 3699 (1977)

67. P.Warneck, J. Geophys. Res. 72, 1651 (1967)

68. P.Warneck, Planet. Space Sci. 15, 1349 (1967)

69. F.V.Wolf, Ann. der Physik. 5, 21 (1937)

II. Tables of Experimental Data

A) Electron Capture Cross Sections of Nitrogen Ions; N^+, N^{2+}, N^{3+}, N^{4+}, N^{5+}, N^{6+} and N^{7+}

(σ_{10})

Wolf	1937	20-1,000	H_2,N_2,Ar	69
Hasted	1951	25-900	Ar	28
Potter	1954	20-250	N_2,O_2	52
Gilbody,Hasted	1956	10-40,000	H_2	26
de Heer et al.	1957	5,000-20,000	H_2,Ne,Ar	7,8
Stebbings et al.	1960	400-10,000	H	61
Nikolaev et al.	1961	490,000-2,440,000	He,N_2,Ar,Kr	47
Il'in,Solov'ev	1961	5,400-186,000	Ar	34
Fite et al.	1962	300°K	O_2	20
Flaks,Ogurtsov	1963	1,000-30,000	H_2	22
Stebbings et al.	1963	40-10,000	O	61
Ferguson et al.	1965	300°K	O_2	19
Pivovar et al.	1966	300,000-1,400,000	Ne,Ar.Kr	51
Fehsenfeld et al.	1966	300°K	CO,CO_2	18
Goldan et al.	1966	300°K	NO	27
Aquilanti,Volpi	1966	300°K	O_2	1
Warneck	1967	0.15	O_2	67,68
Turner,Rutherford	1968	2-400	H_2O	65
Belyaev et al.	1968	7-100	N	2
Dunkin et al.	1968	300-550°K	O_2	16
Johnsen et al.	1970	0.04-0.85	O_2	35
Kaneko et al.	1970	0.04-1.8	O_2	36

Ormrod,Michel	1971	15,000-85,000	N_2,Ar	49
Lo et al.	1971	30,000-2,000,000	O	42
Maier	1971	10-32	N_2	43
Rutherford et al.	1971	3-400	Mg	54
Rutherford et al.	1972	2-500	Ca	56
Rutherford,Vroom	1972	3-500	Fe	57
Rutherford,Vroom	1975	2-400	Kr,CO	59
Kosmider,Hasted	1975	0.4-10	N_2,NO	39
Phaneuf et al.	1977	6,500-450,000	H	50
Vujović et al.	1977	2,000-30,000	He,Ne,Ar, Kr,Xe	66
Meyer et al.	1977	30,000-140,000	Cs	45

(σ_{21})

Nikolaev et al.	1957	1,280,000-2,600,000	N_2	46
Nikolaev et al.	1961	490,000-6,300,000	He,N_2,Ar,Kr	47
Flaks,Ogurtsov	1963	6,000-60,000	H_2	22
Ormrod,Michel	1971	30,000-90,000	N_2,Ar	49
Hasted et al.	1971	1,000-3,000	He,Ne,Ar	31
Teplova et al.	1975	230,000	N_2	63
Phaneuf et al.	1977	40,000-600,000	H	50

(σ_{20})

Nikolaev et al.	1962	490,000-2,440,000	He,N_2,Ar,Kr	48
Flaks,Ogurtsov	1963	6,000-60,000	H_2	22

(σ_{32})

Nikolaev et al.	1957	1,280,000-4,600,000	N_2	46
Nikolaev et al.	1961	490,000-6,300,000	He,N_2,Ar,Kr	47
Flaks,Ogurtsov	1963	9,000-90,000	H_2	22
Teplova et al.	1975	230,000	N_2	63
Crandall	1975	15,000-55,000	H_2	4
Crandall et al.	1977	15,000-70,000	H_2	5
Phaneuf et al.	1977	60,000-1,300,000	H	50

(σ_{31})

Nikolaev et al.	1962	490,000-6,200,000	He,N_2,Ar,Kr	48
Flaks,Ogurtsov	1963	9,000-90,000	H_2	22

(σ_{30})

Nikolaev et al.	1962	490,000	N_2,Ar,Kr	48

(σ_{43})

Nikolaev et al.	1957	260,000-10,000,000	N_2	46
Nikolaev et al.	1961	490,000-10,100,000	He,N_2,Ar,Kr	47
Teplova et al.	1975	230,000	N_2	63
Crandall et al.	1977	22,000-80,000	H_2	5
Phaneuf et al.	1977	600,000-1,700,000	H	50

(σ_{42})

Nikolaev et al.	1962	490,000-10,100,000	He,N_2,Ar,Kr	48

(σ_{41})				
Nikolaev et al.	1962	490,000-2,400,000	N_2,Ar,Kr	48
(σ_{40})				
Nikolaev et al.	1962	490,000	N_2,Ar	48
(σ_{54})				
Nikolaev et al.	1961	490,000-10,100,000	He,N_2,Ar,Kr	47
Teplova et al.	1975	230,000	N_2	63
Dmitriev et al.	1975	4,640,000-10,440,000	He,N_2	15
Crandall et al.	1977	30,000-105,000	H_2	5
Crandall	1977	30,000-106,000	He	6
Phaneuf et al.	1977	750,000-1,700,000	H	50
(σ_{53})				
Nikolaev et al.	1961	2,440,000-10,100,000	He,N_2,Ar,Kr	48
Dmitriev et al.	1975	4,640,000-10,440,000	He,N_2	15
Crandall et al.	1977	30,000-75,000	H_2	5
Crandall	1977	30,000-106,000	He	6
(σ_{52})				
Nikolaev et al.	1962	2,400,000-4,640,000	N_2,Ar,Kr	48
(σ_{51})				
Nikolaev et al.	1962	2,440,000	N_2	48

(σ_{65})

Reynolds et al.	1955	26,000,000	Zapon film	53
Nikolaev et al.	1961	3,760,000-10,100,000	He,N_2,Ar,Kr	47
Teplova et al.	1975	230,000	N_2	63

(σ_{64})

Nikolaev et al.	1962	3,550,000-10,100,000	N_2,Ar,Kr	48

(σ_{63})

Nikolaev et al.	1962	3,760,000-10,100,000	N_2,Ar,Kr	48

(σ_{76})

Reynolds et al.	1955	26,000,000	Zapon film	53

B) Electron Loss Cross Sections of Nitorgen Negative Ion, Atom and Positive Ions; N^-, N°, N^+, N^{2+}, N^{3+}, N^{4+}, N^{5+}, N^{6+}.

($\sigma_{\bar{1}0}$)

Dmitriev et al.	1966	490,000	He,N_2, Ar	11

($\sigma_{\bar{1}1}$)

Dmitriev et al.	1966	490,000	He,N_2,Ar	11

($\sigma_{\bar{1}2}$)

Dmitriev et al.	1966	490,000	N_2,Ar	11

(σ_{01})

Dmitriev et al.	1962	490,000-2,440,000	He,N_2,Ar,Kr	9
Dmitriev et al.	1966	490,000	He,N_2,Ar	11
Ormrod,Michel	1971	20,000-100,000	N_2,Ar	49

(σ_{12})

Fedorenko	1954		H_2,He,N_2, Ne,Ar	17
Korsunsky et al.	1955	485,000-1,180,000	N_2	38
de Heer et al.	1957	5,000-20,000	H_2,Ar	7,8
Nikolaev et al.	1957	1,280,000-2,600,000	N_2	46
Dmitriev et al.	1962	490,000-3,600,000	He,N_2,Ar,Kr	9
Pivovar et al.	1966	300,000-1,400,000	Ne,Ar,Kr	51
Dmitriev et al.	1966	490,000	He,N_2,Ar	11
Lo et al.	1971	64,000-2,038,000	O	42
Hird,Suk	1976	35,000-140,000	Ne	33
Vujović	1977	2,000-30,000	He,Ne	66

(σ_{13})

Dmitriev et al.	1963	490,000-3,600,000	He,N_2,Ar,Kr	10
Pivovar et al.	1966	300,000-1,400,000	Ne,Ar,Kr	51
Dmitriev et al.	1966	490,000	He,N_2,Ar	11
Lo et al.	1971	145,000-2,038,000	O	42

(σ_{14})

Korsunsky et al.	1955		N_2	38
Dmitriev et al.	1963	490,000-3,600,000	He,N_2,Ar,Kr	10

Pivovar et al.	1966	400,000-1,400,000	Ne,Ar,Kr	51
Dmitriev et al.	1966	490,000	N_2,Ar	11
Lo et al.	1971	195,000-2,038,000	O	42
(σ_{15})				
Korsunsky et al.	1955		N_2	38
Dmitriev et al.	1963	2,440,000	Ar,Kr	10
Pivovar et al.	1966	900,000-1,400,000	Ne,Ar,Kr	51
Lo et al.	1971	1,434,000-2,038,000	O	42
(σ_{23})				
Nikolaev et al.	1957	1,280,000-2,600,000	N_2	46
Dmitriev et al.	1962	490,000-6.140,000	He,N_2,Ar,Kr	9
Dmitriev et al.	1966	490,000	He,N_2,Ar	11
Teplova et al.	1975	230,000	N_2	63
(σ_{24})				
Dmitriev et al.	1963	490,000-6,140,000	He,N_2,Ar,Kr	10
Dmitriev et al.	1966	490,000	He,N_2,Ar	11
(σ_{25})				
Dmitriev et al.	1963	2,440,000-6,140,000	He,N_2,Ar, Kr	10
(σ_{34})				
Nikolaev et al.	1957	2,600,000-5,120,000	N_2	46
Dmitriev et al.	1962	490,000-6,140,000	He,N_2,Ar,Kr	9

Dmitriev et al.	1966	490,000	He,N_2,Ar	11
Teplova et al.	1975	230,000	N_2	63
(σ_{35})				
Dmitriev et al.	1963	2,440,000-6,140,000	He,N_2,Ar,Kr	10
(σ_{45})				
Nikolaev et al.	1957	9,600,000	N_2	46
Dmitriev et al.	1962	1,280,000-10,100,000	He,N_2,Ar,Kr	9
Tonuma et al.	1970	45,000,000-85,000,000	N_2	64
Teplova et al.	1975	230,000	N_2	63
(σ_{46})				
Dmitriev et al.	1963	6,140,000-10,100,000	He,N_2,Ar,Kr	10
(σ_{56})				
Reynolds et al.	1955	26,000,000	Zapon film	53
Dmitriev et al.	1962	2,440,000-10,100,000	He,N_2,Ar,Kr	9
Teplova et al.	1975	230,000	N_2	63
Dmitriev et al.	1975	4,640,000-10,440,000	He,N_2	15
(σ_{57})				
Dmitriev et al.	1963	10,100,000	N_2,Kr	10
Dmitriev et al.	1975	10,440,000	He,N_2	15

(σ_{67})

Reynolds et al.	1955	26,000,000	Zapon film	53
Dmitriev et al.	1962	4,600,000-10,300,000	He,N_2,Ar,Kr	9
Teplova et al.	1975	230,000	N_2	63

C) Ionization Cross Sections, Slow ion and Electron Production by Nitrogen Atom and Ions

(σ_0^i, σ_0^+, σ_0^-)

Flaks,Ogurtsov	1963	1,000-30,000	H_2	22

(σ_1^i, σ_1^+, σ_1^-)

Hasted	1951	25-900	Ar	17
Gilbody,Hasted	1956	10-40,000	H_2	26
de Heer et al.	1957	5,000-20,000	H_2,Ne,Ar	7,8
Il'in,Solov'ev	1961	5,400-186,000	Ar	34
Flaks,Ogurtsov	1963	1,000-30,000	H_2	22
Hippler,Schartner	1975	100,000-1,000,000	Ne,Ar,Kr	32

(σ_2^i, σ_2^+, σ_2^-)

Flaks,Ogurtsov	1963	4,000-60,000	H_2	22

(σ_3^i, σ_3^+, σ_3^-)

Flaks,Ogurtsov	1963	9,000-90,000	H_2	22

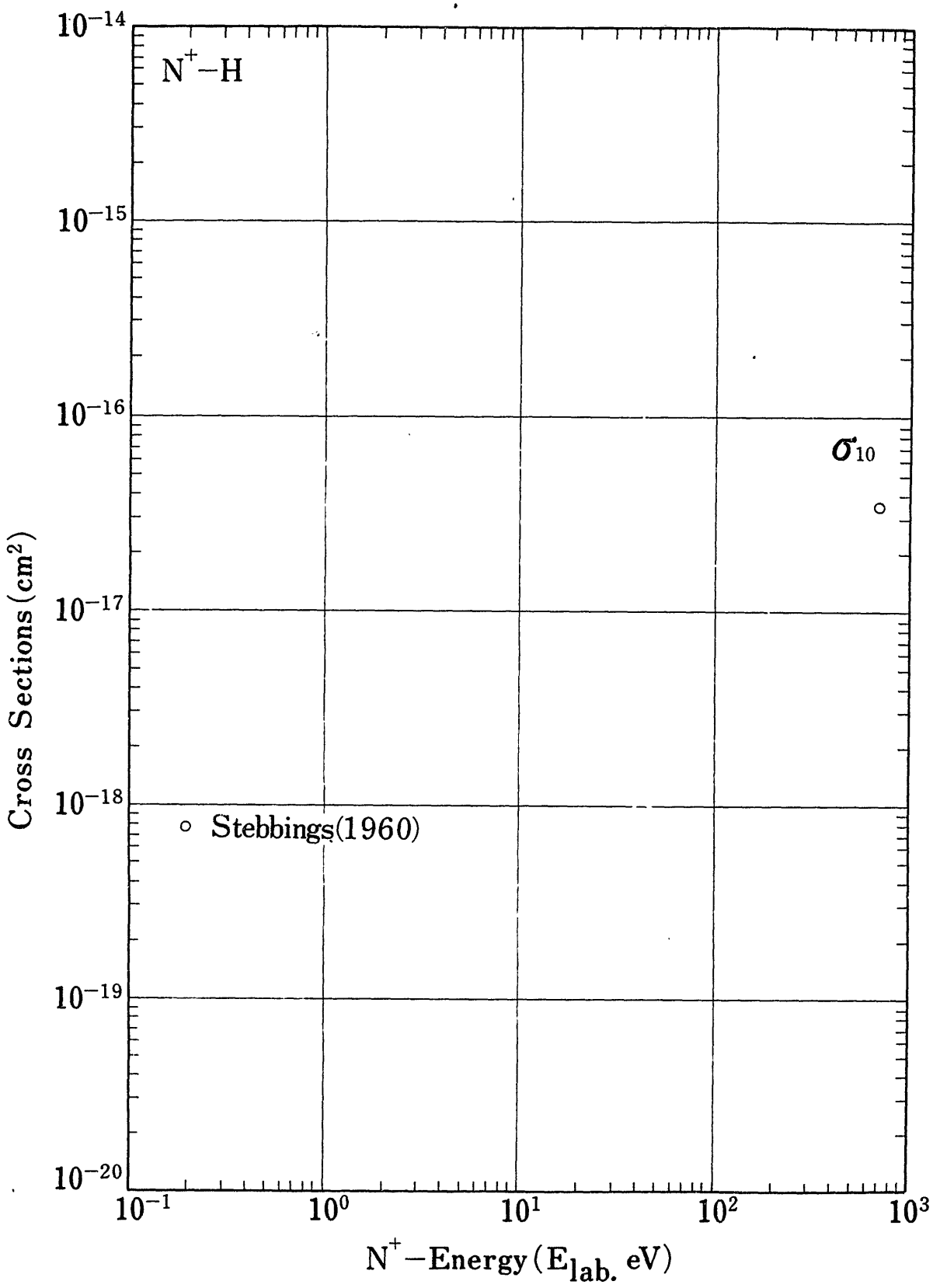


Fig. 1−a Charge Changing Cross Sections of N^+ in H

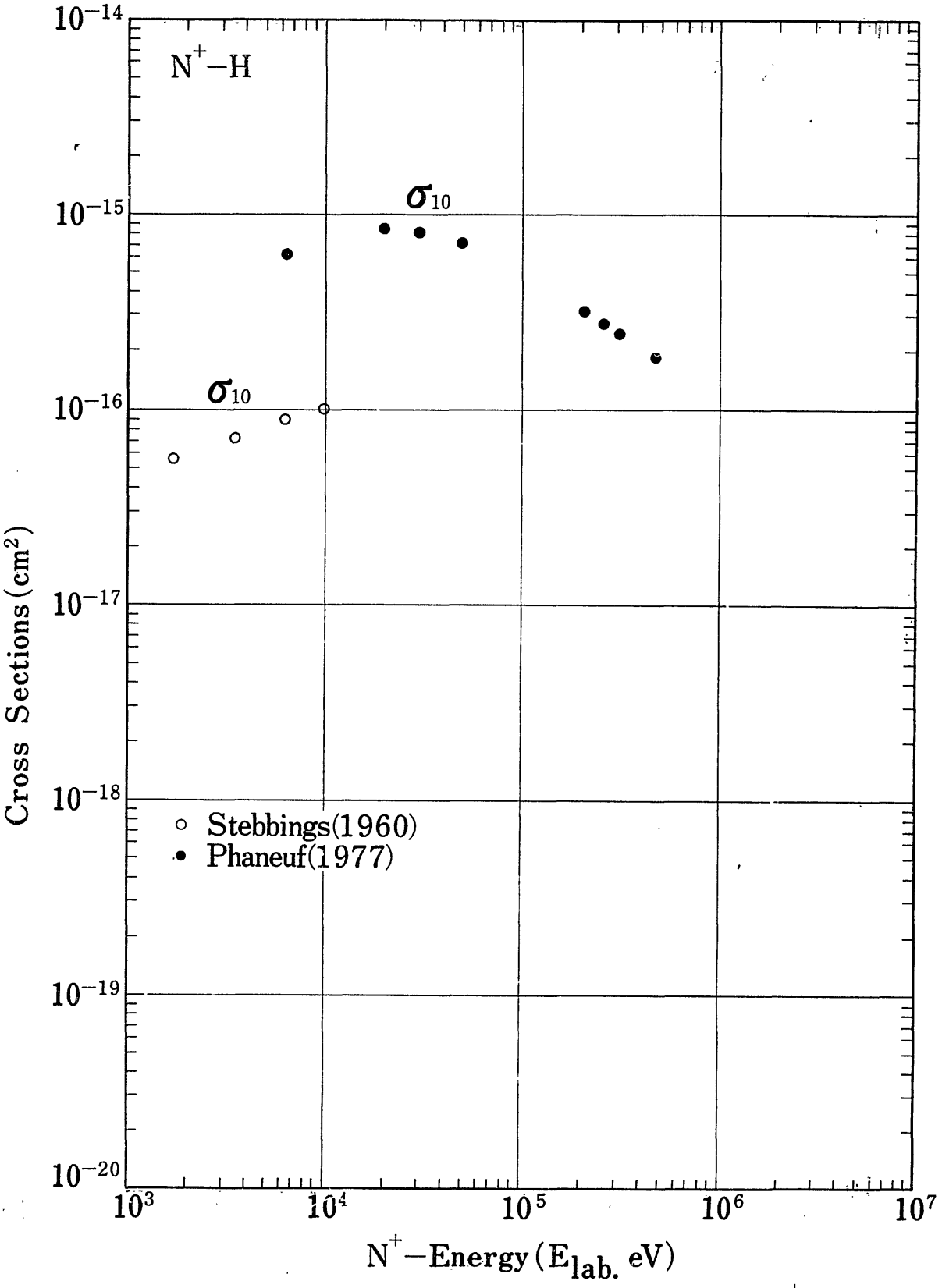


Fig.1−b Charge Changing Cross Sections of N^+ in H

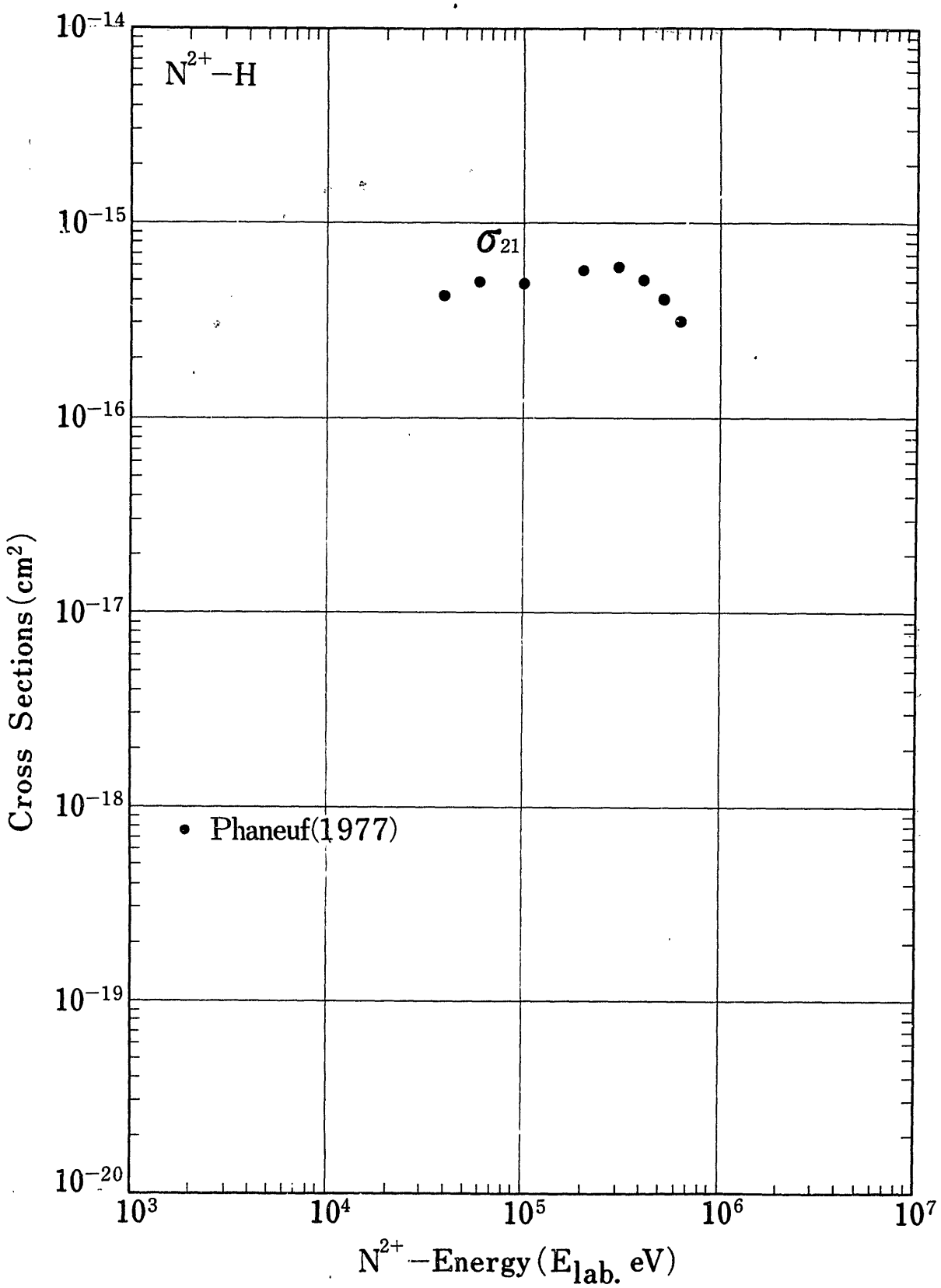


Fig. 2 Charge Changing Cross Sections of N^{2+} in H

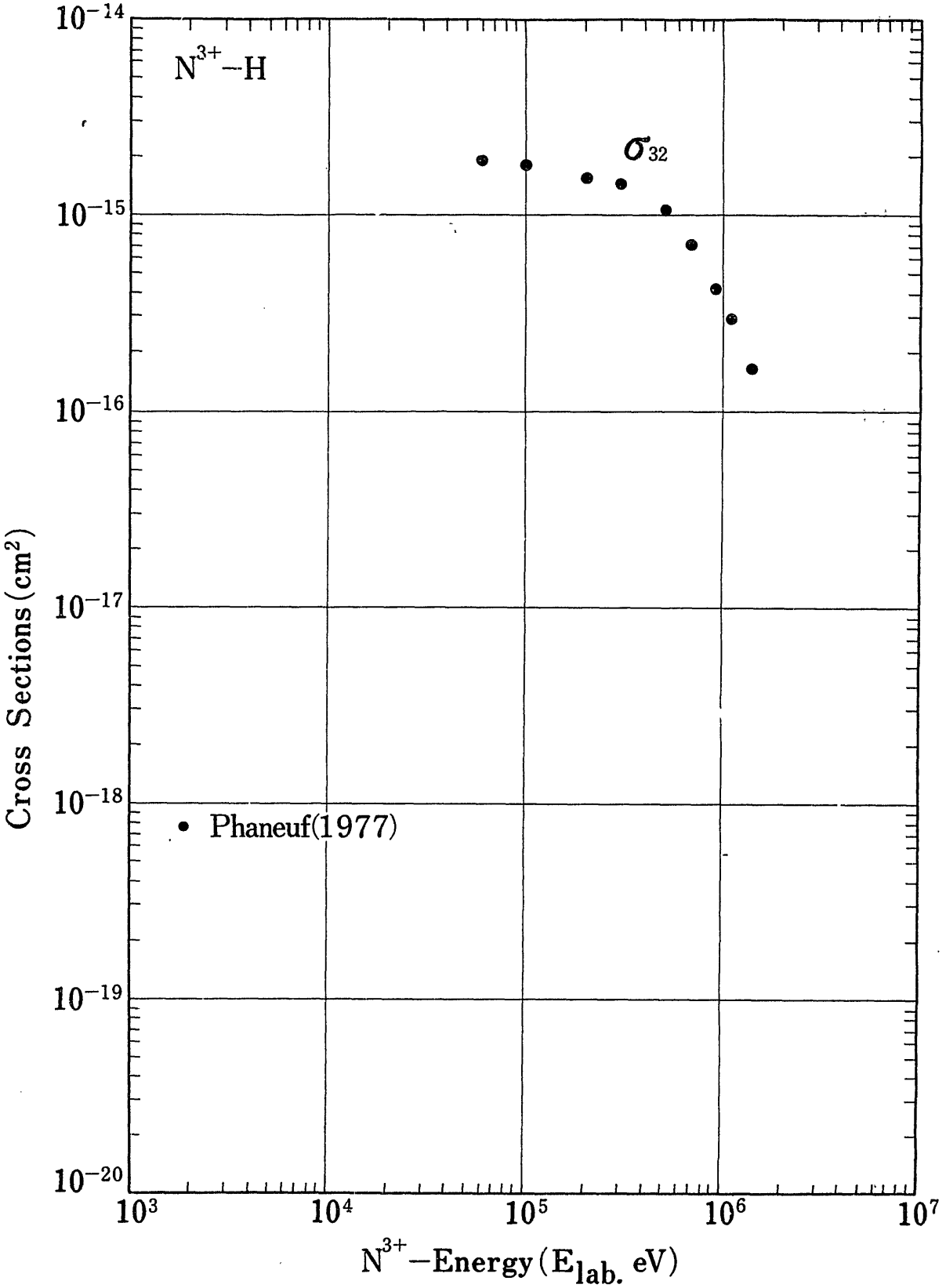


Fig.3 Charge Changing Cross Sections of N^{3+} in H

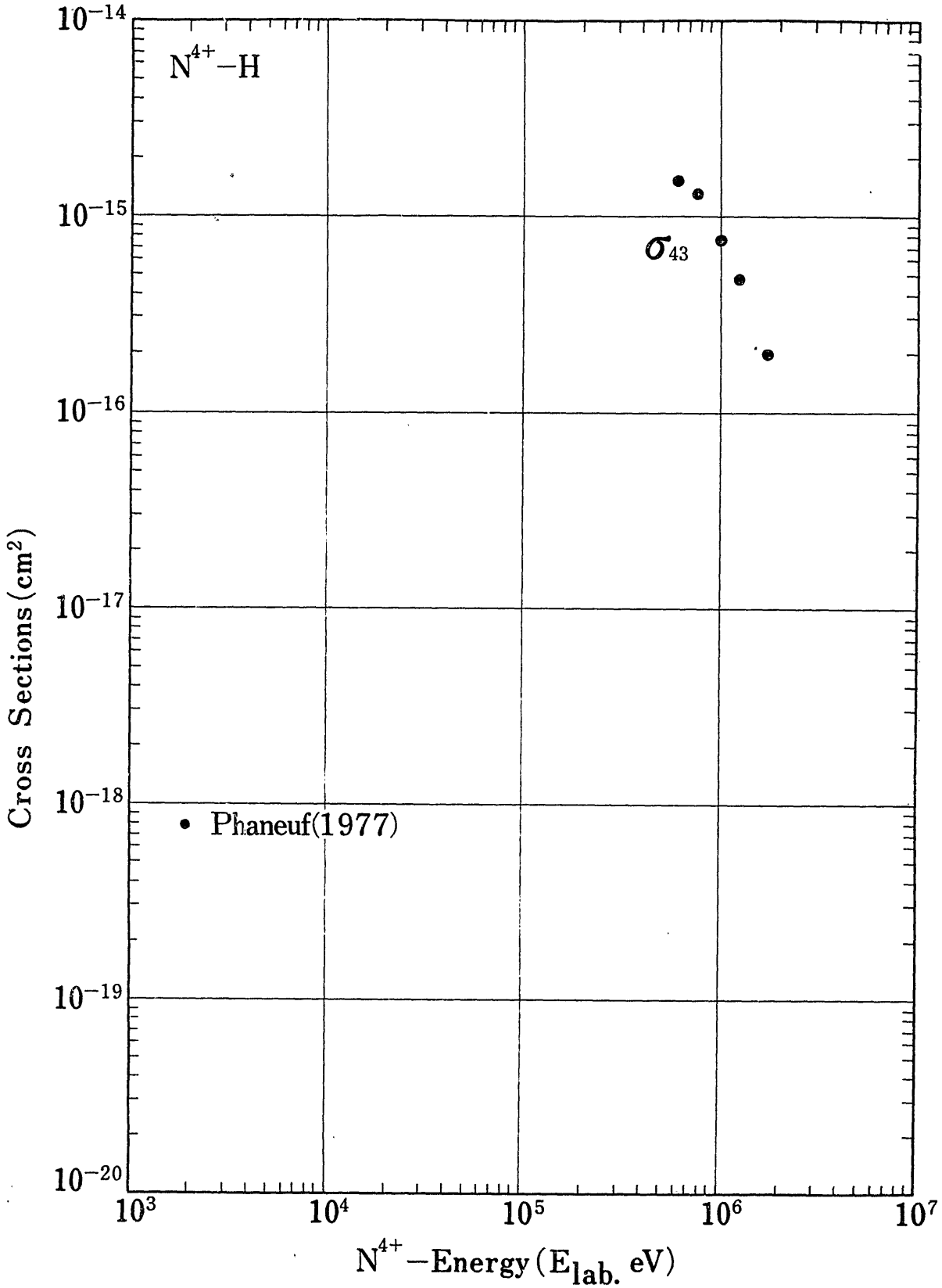


Fig.4 Charge Changing Cross Sections of N^{4+} in H

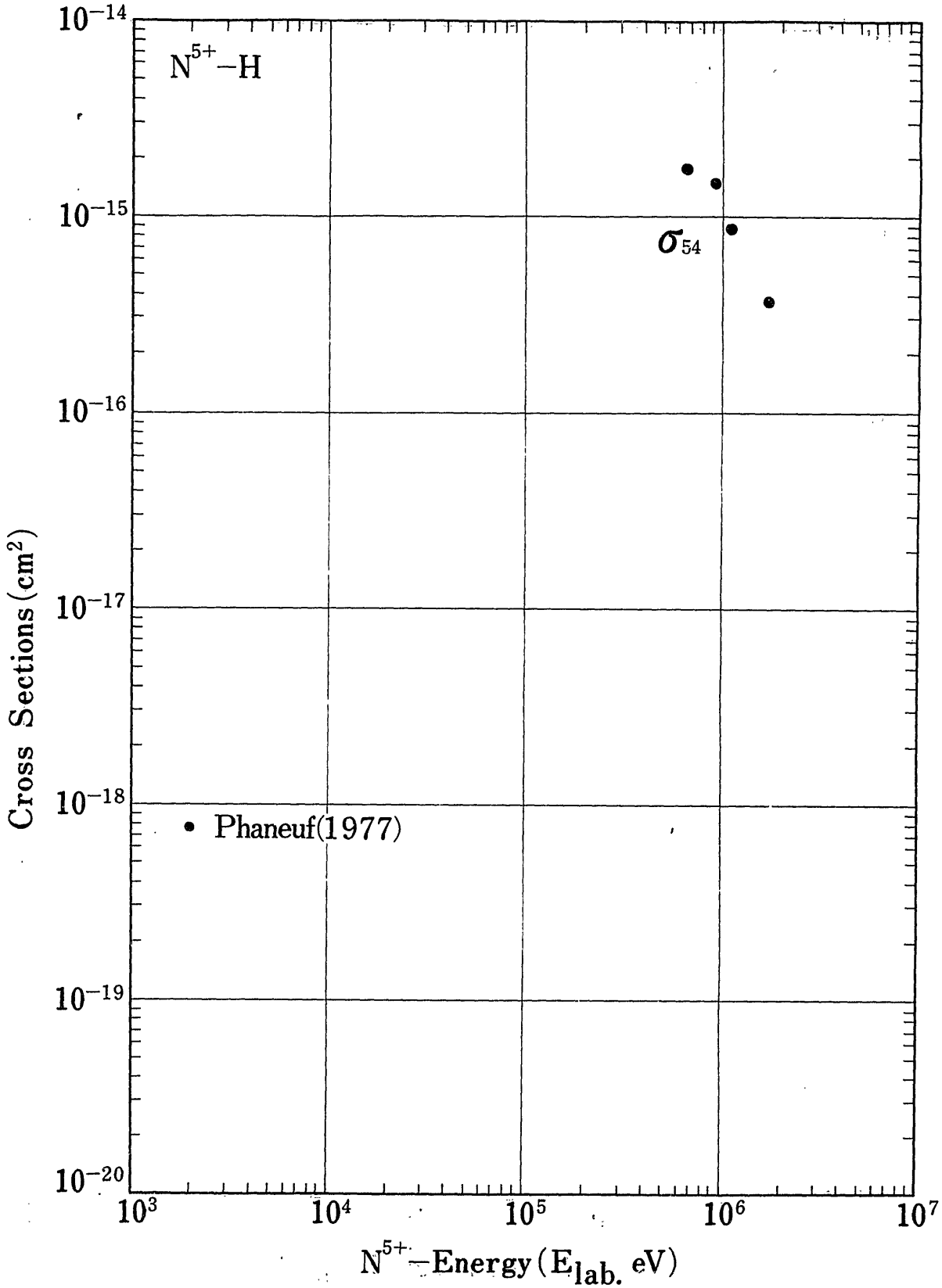


Fig.5 Charge Changing Cross Sections of N^{5+} in H

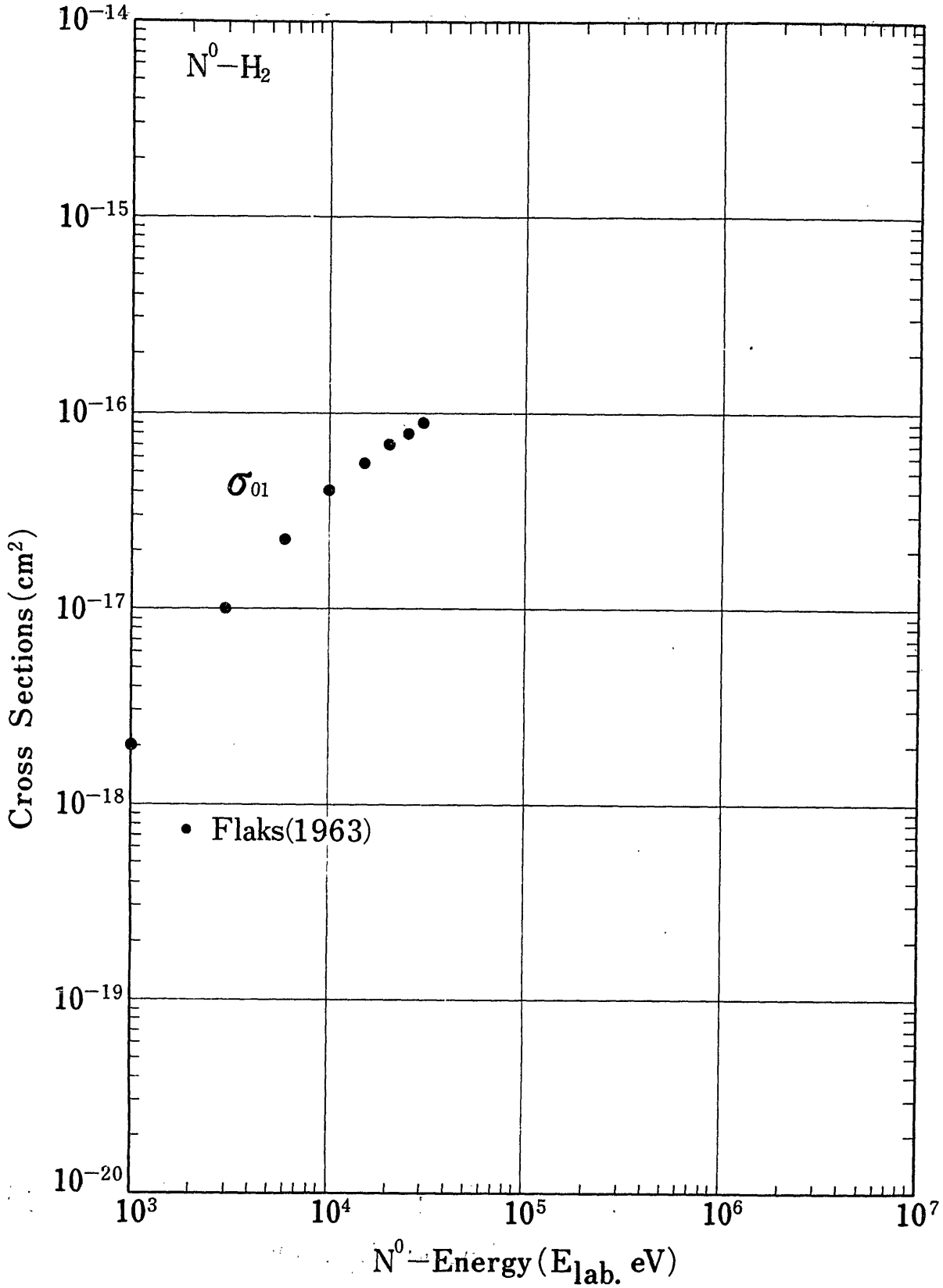


Fig.6 Charge Changing Cross Sections of N^0 in H_2

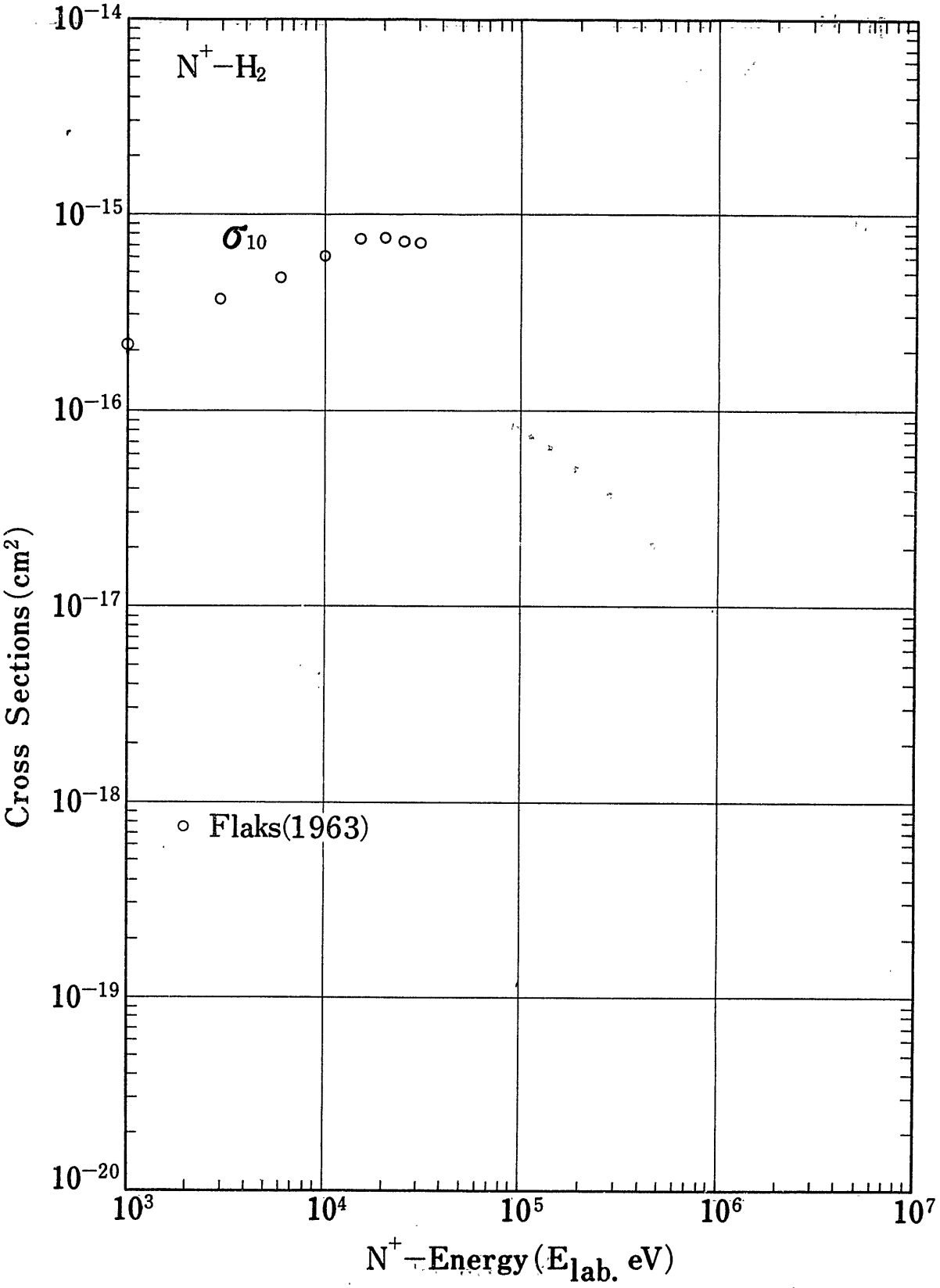


Fig.7 Charge Changing Cross Sections of N^+ in H_2

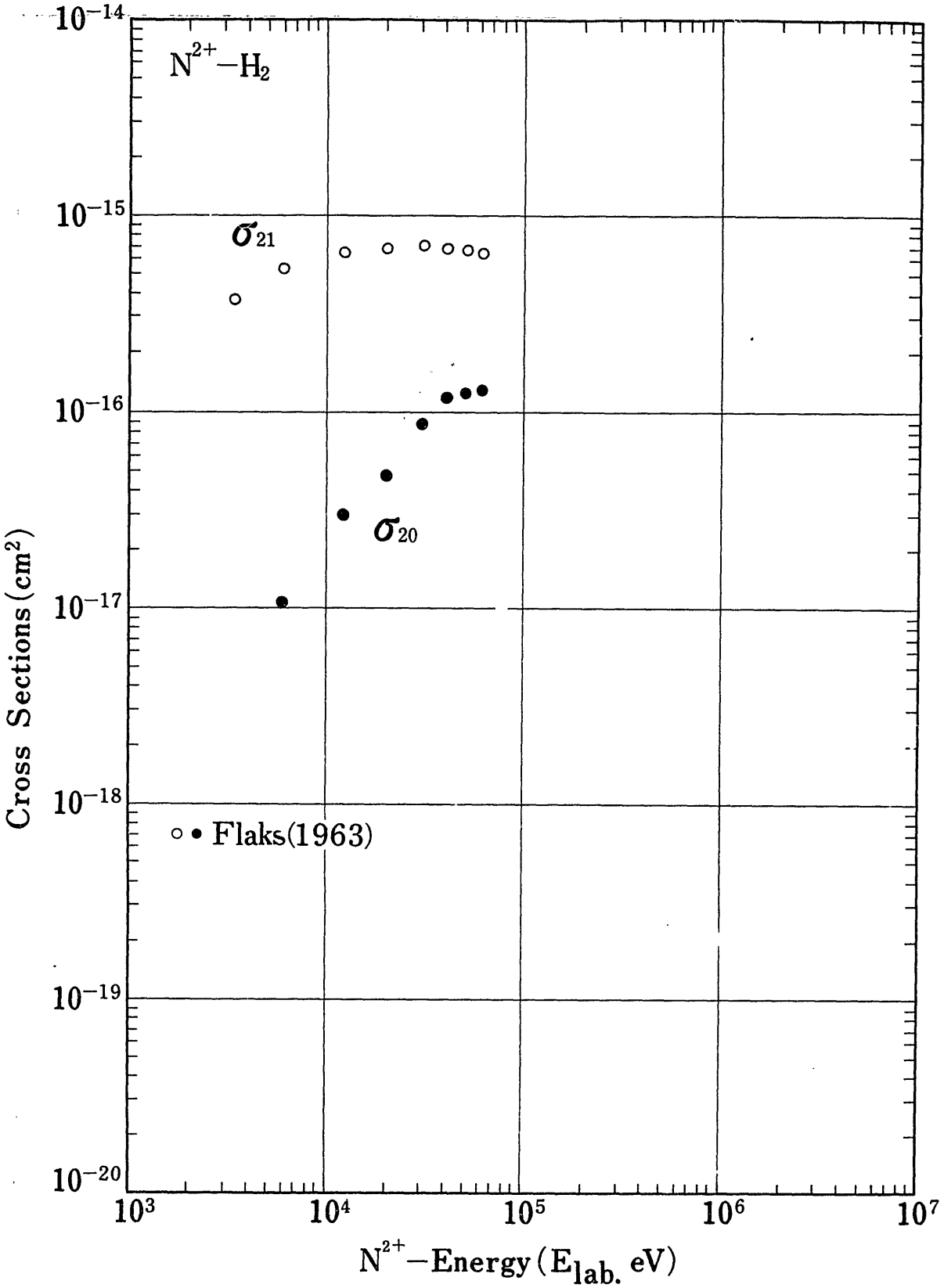


Fig. 8 Charge Changing Cross Sections of N^{2+} in H_2

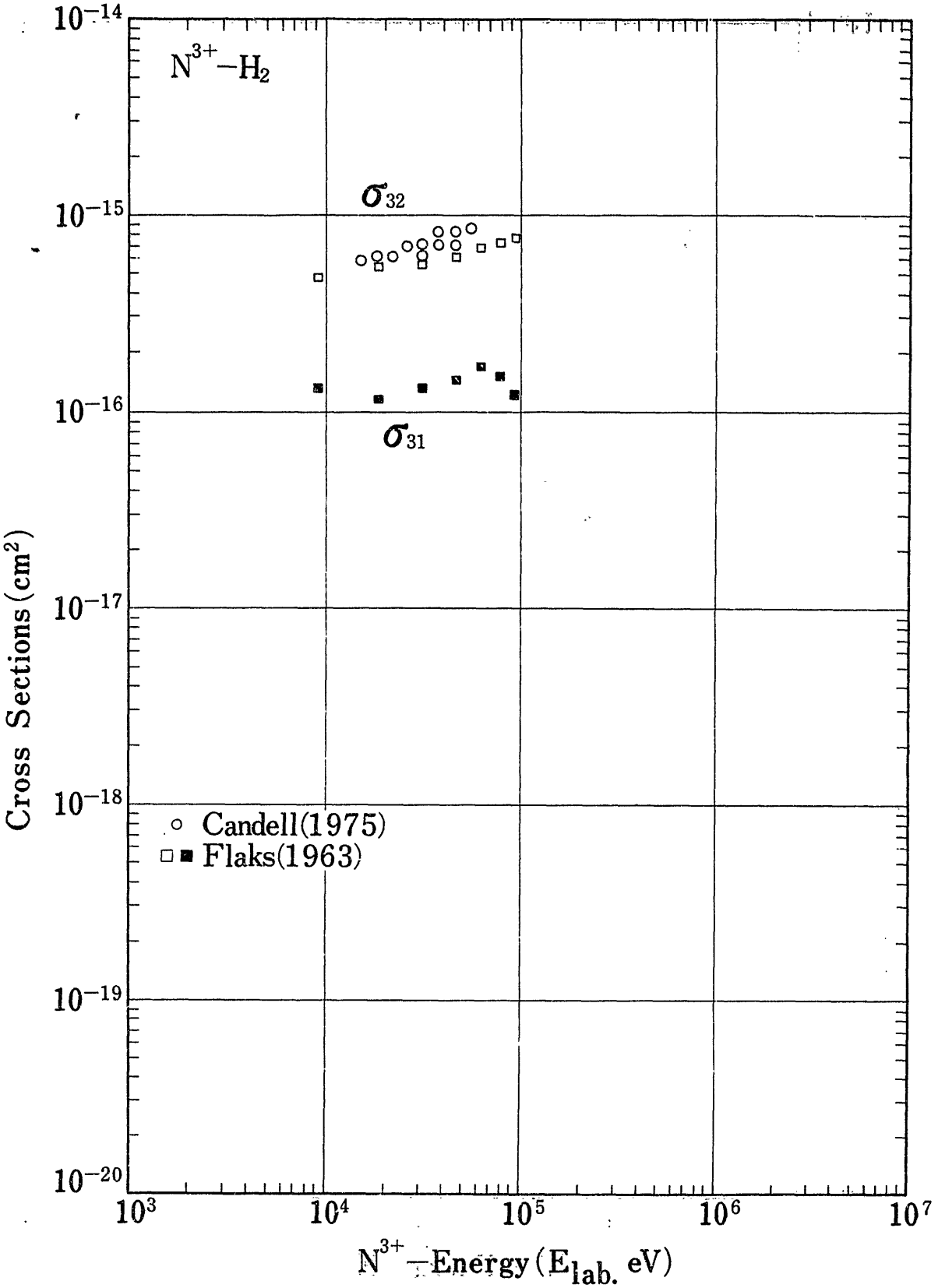


Fig.9 Charge Changing Cross Sections of N^{3+} in H_2

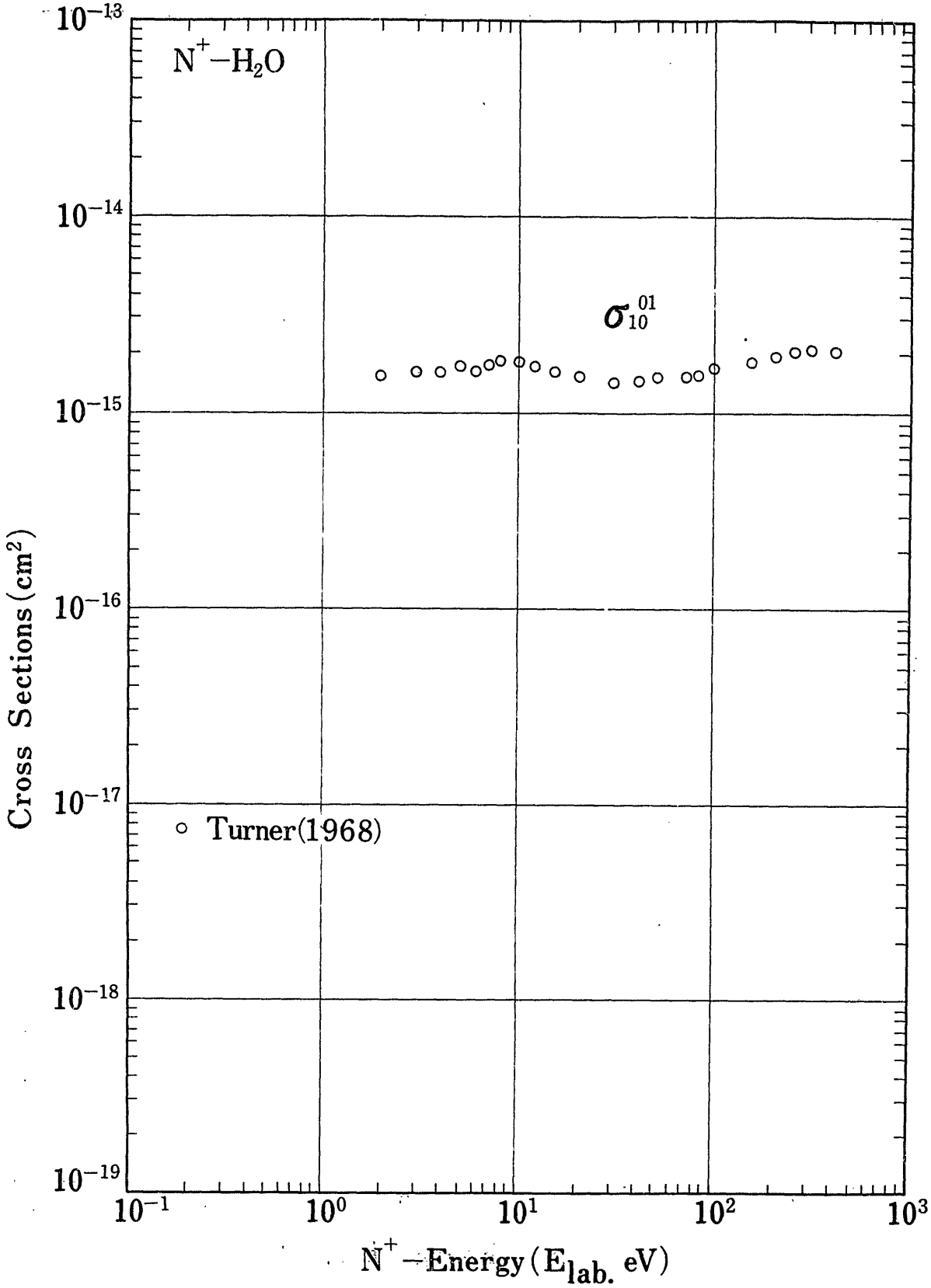


Fig.10 Charge Changing Cross Sections of N^+ in H_2O

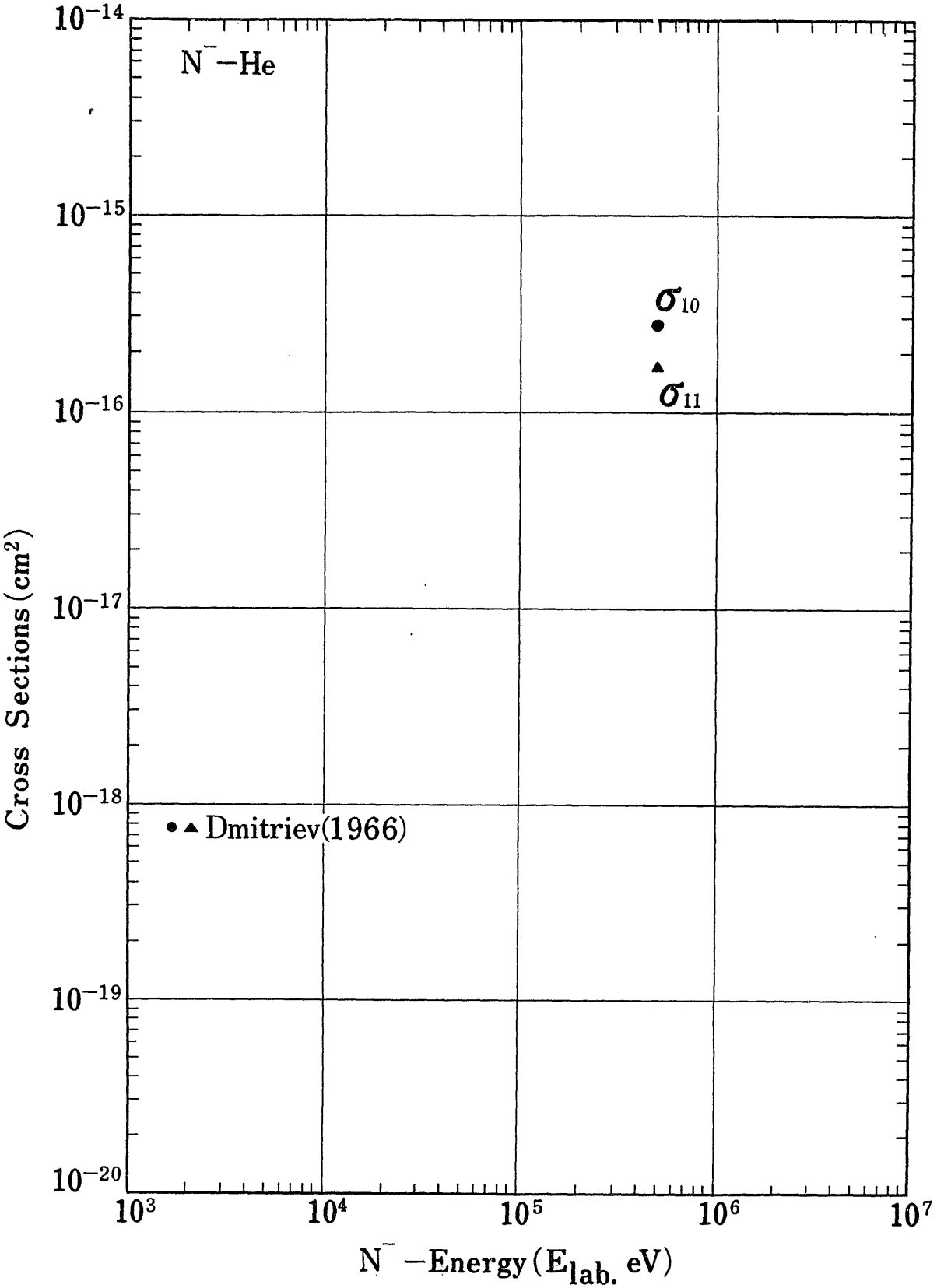


Fig.11 Charge Changing Cross Sections of N^- in He

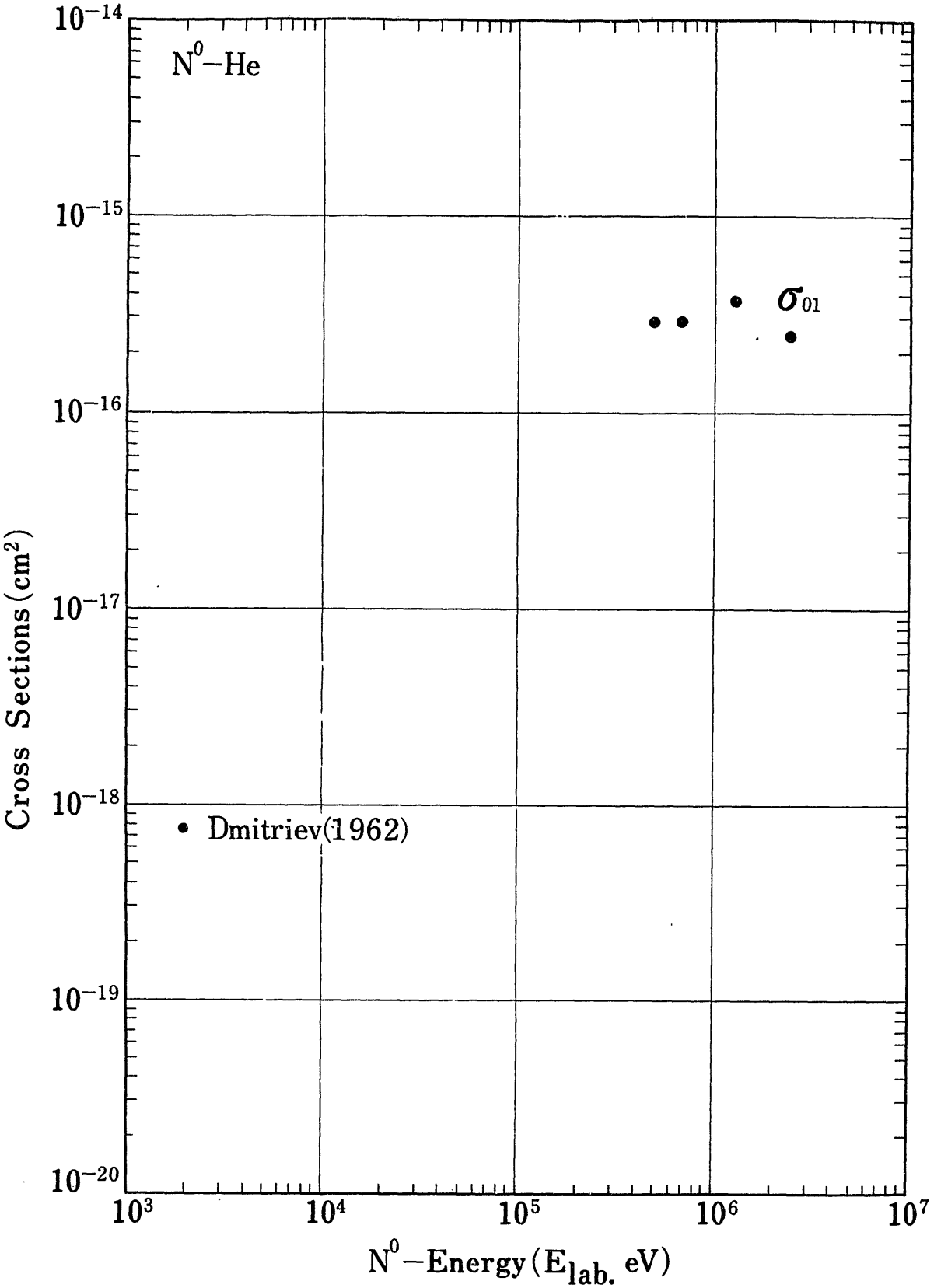


Fig.12 Charge Changing Cross Sections of N^0 in He

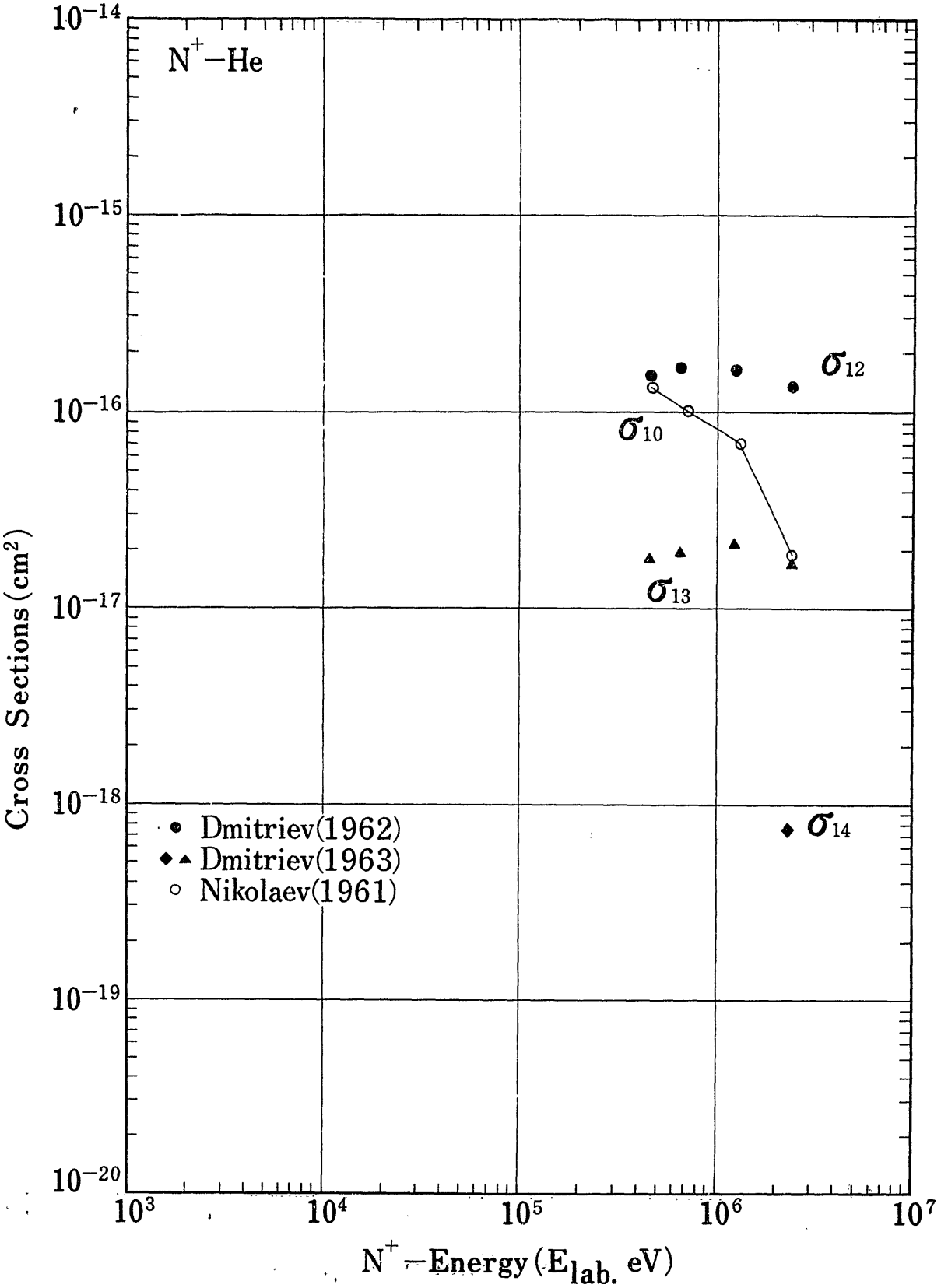


Fig.13 Charge Changing Cross Sections of N^+ in He

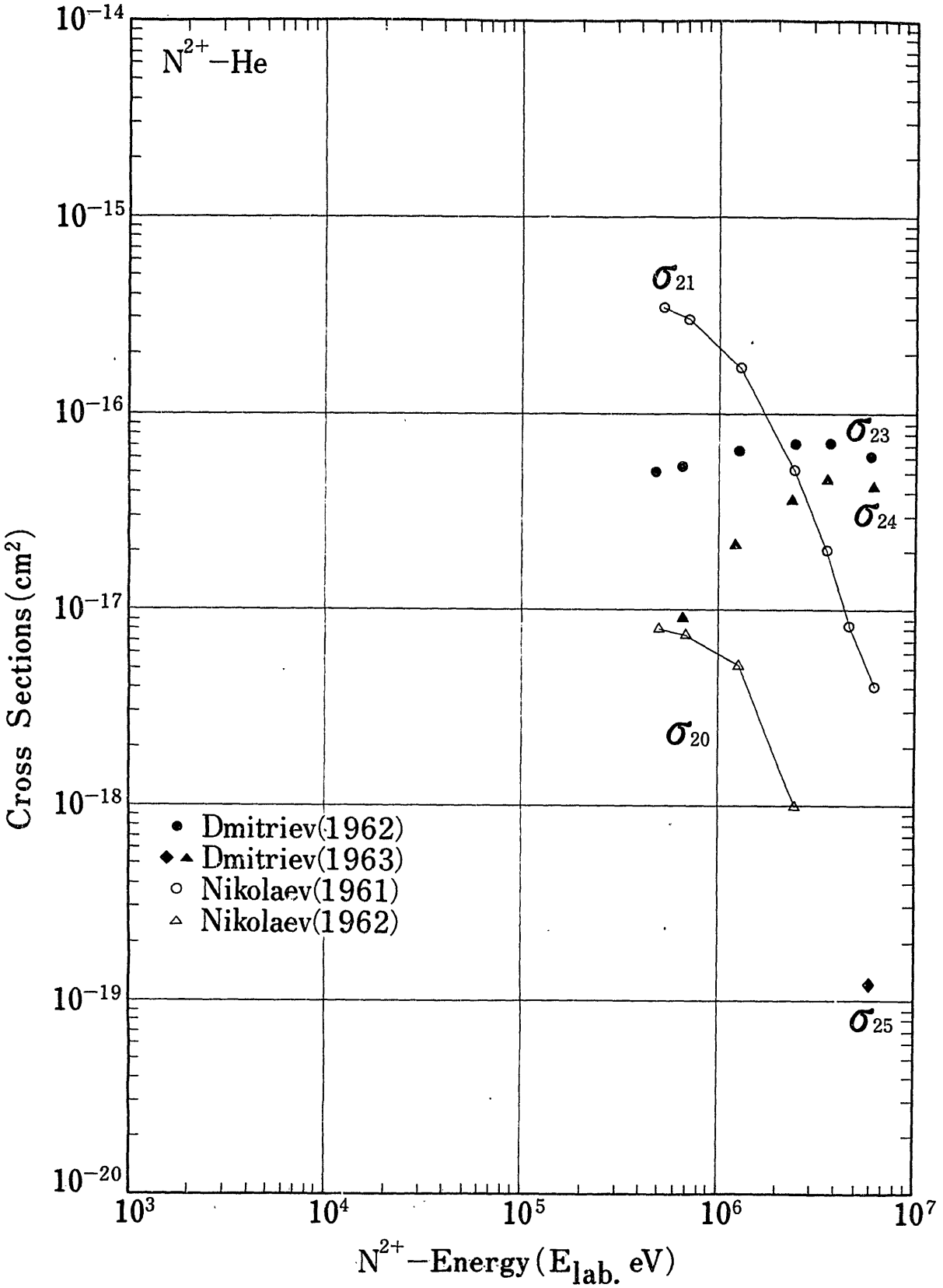


Fig. 14 Charge Changing Cross Sections of N^{2+} in He

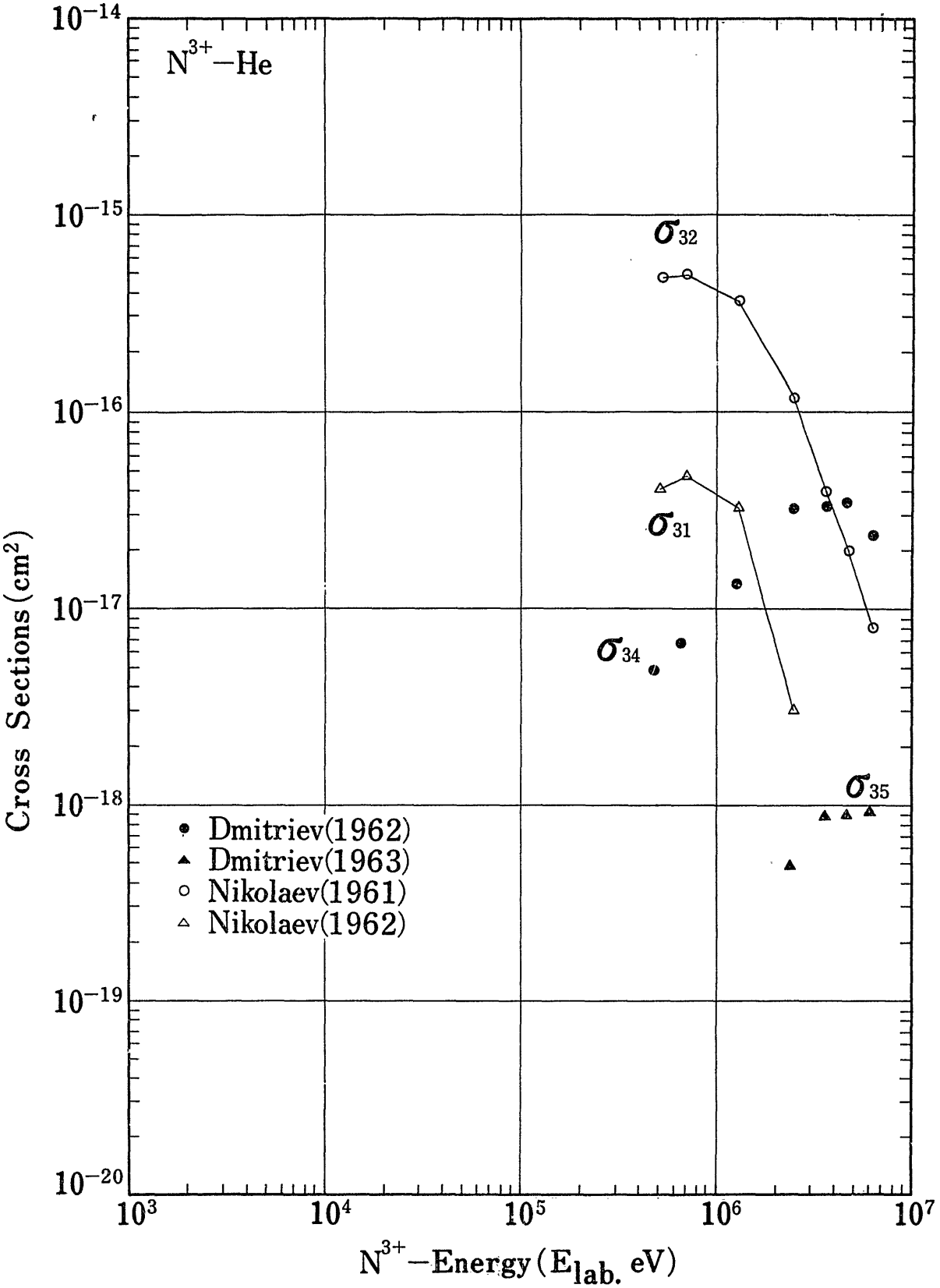


Fig.15 Charge Changing Cross Sections of N^{3+} in He

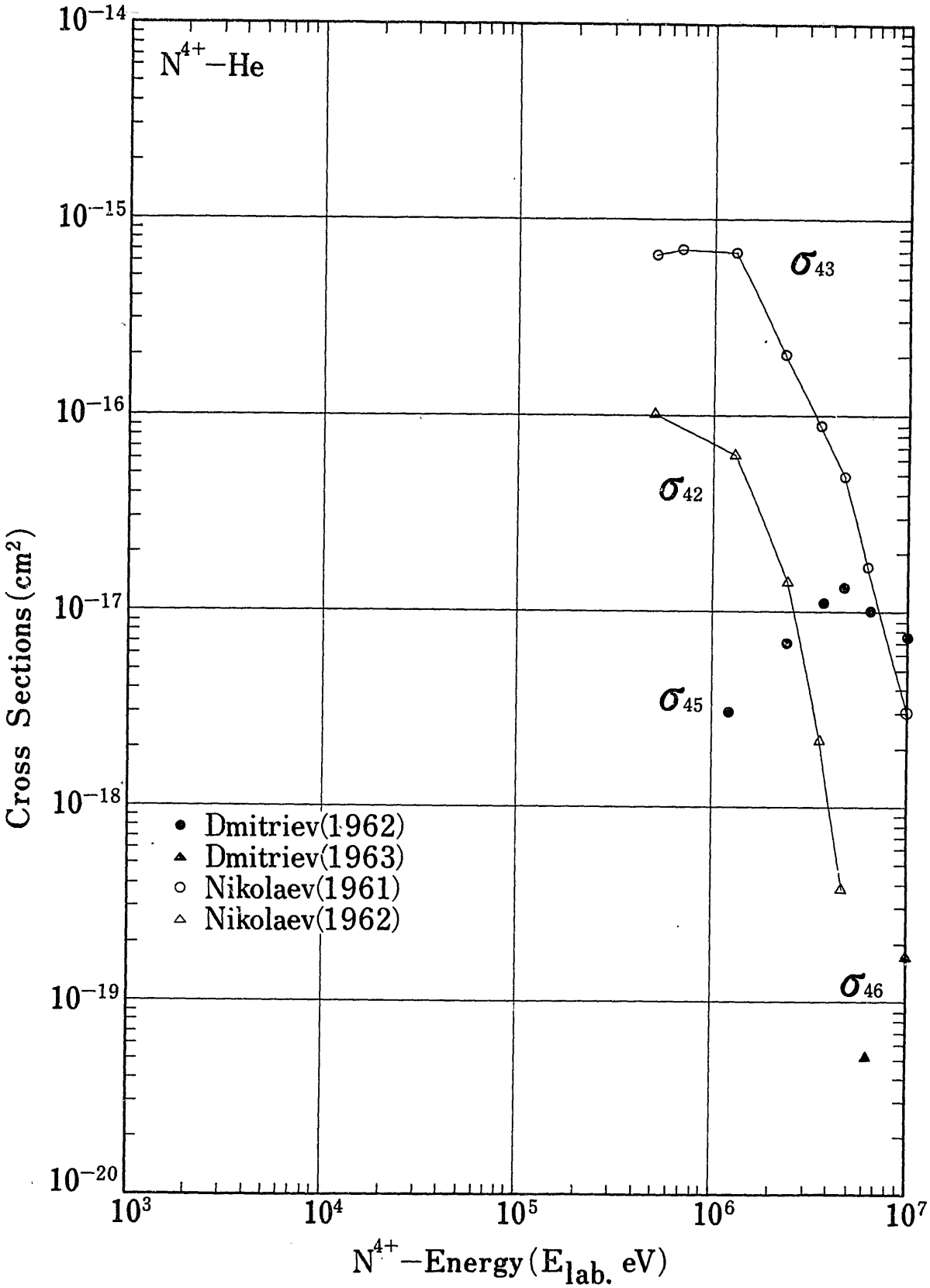


Fig.16 Charge Changing Cross Sections of N^{4+} in He

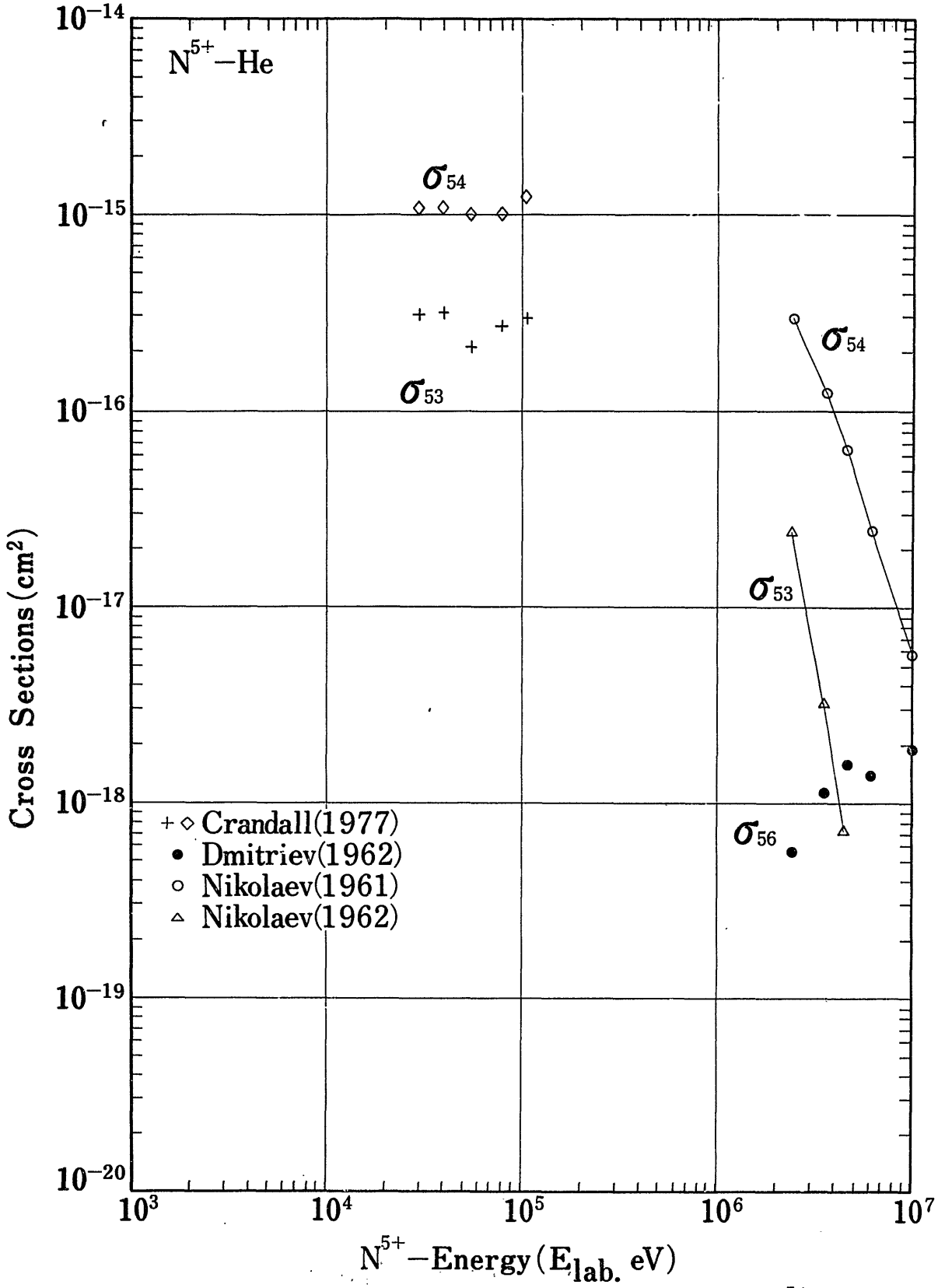


Fig.17 Charge Changing Cross Sections of N^{5+} in He

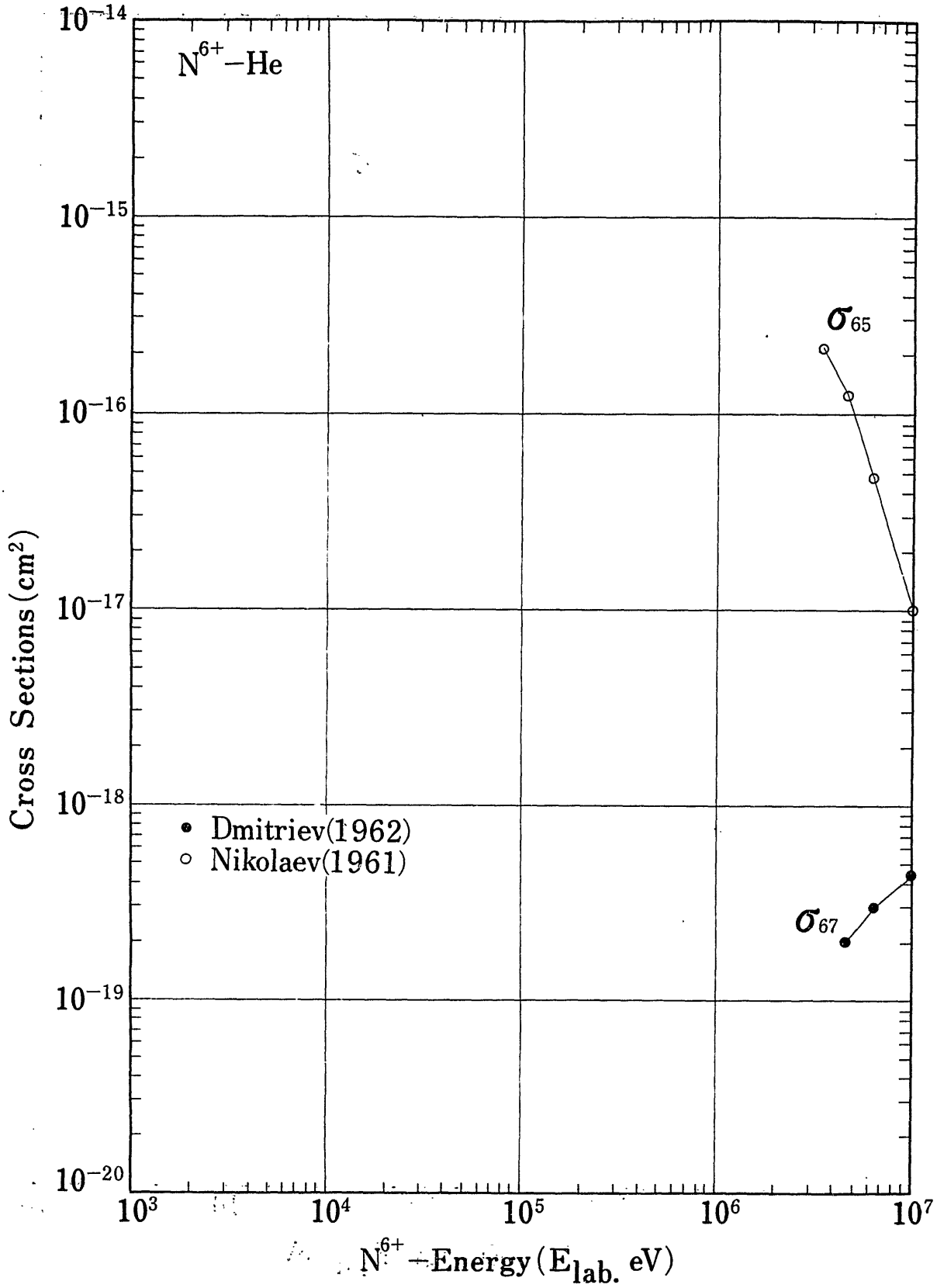


Fig.18 Charge Changing Cross Sections of N^{6+} in He

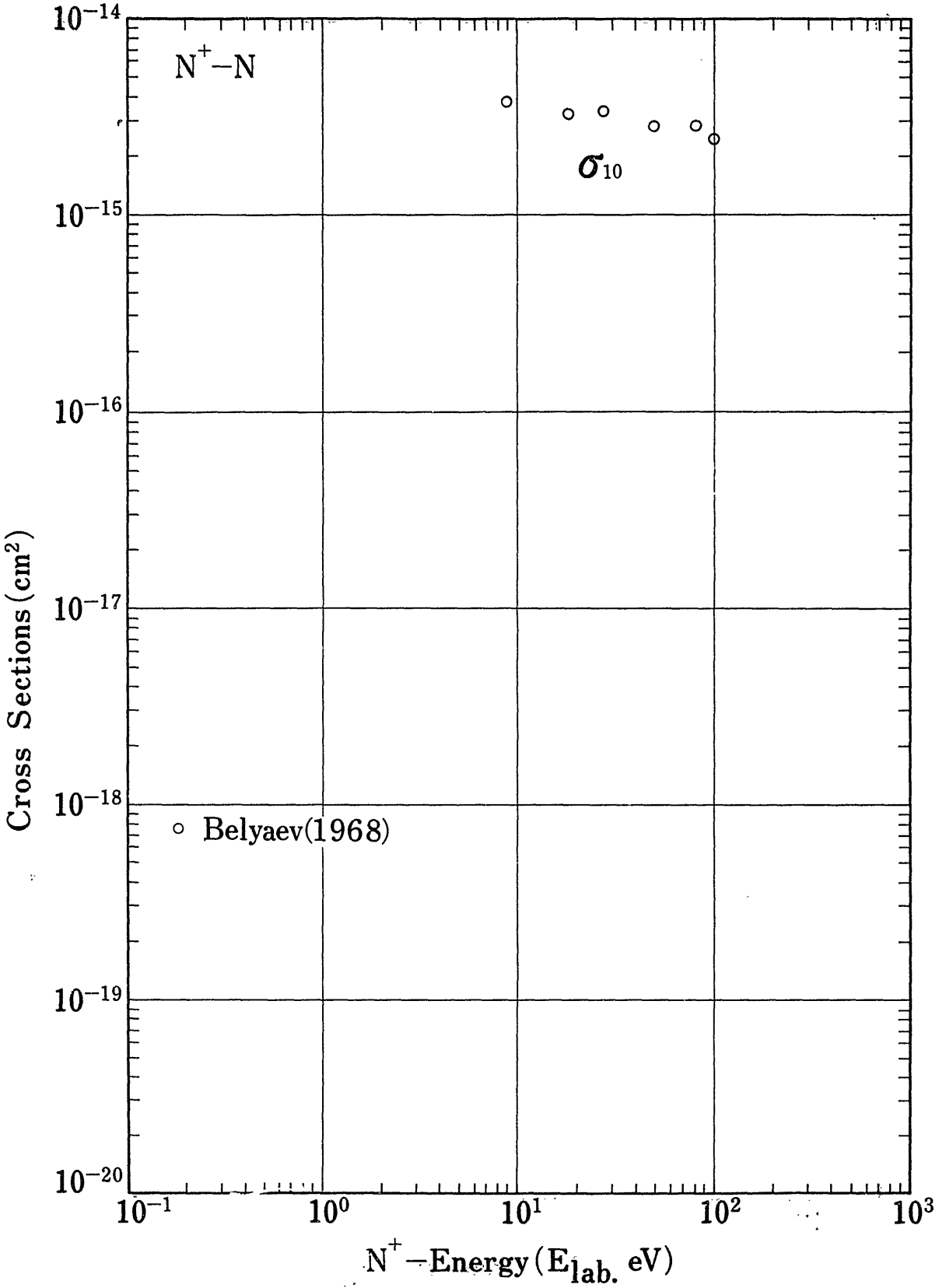


Fig.19 Charge Changing Cross Sections of N^+ in N

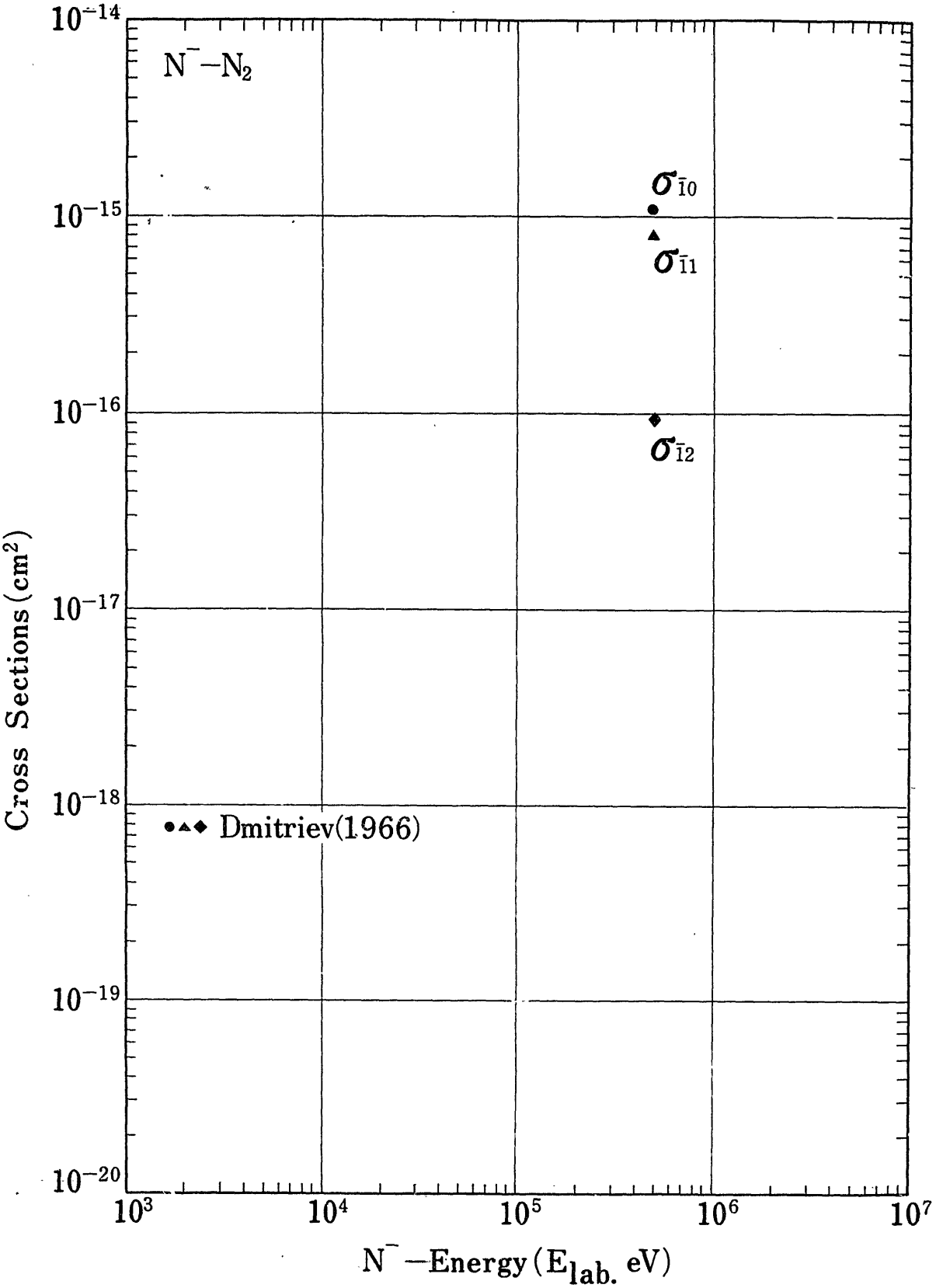


Fig.20 Charge Changing Cross Sections of N^- in N_2

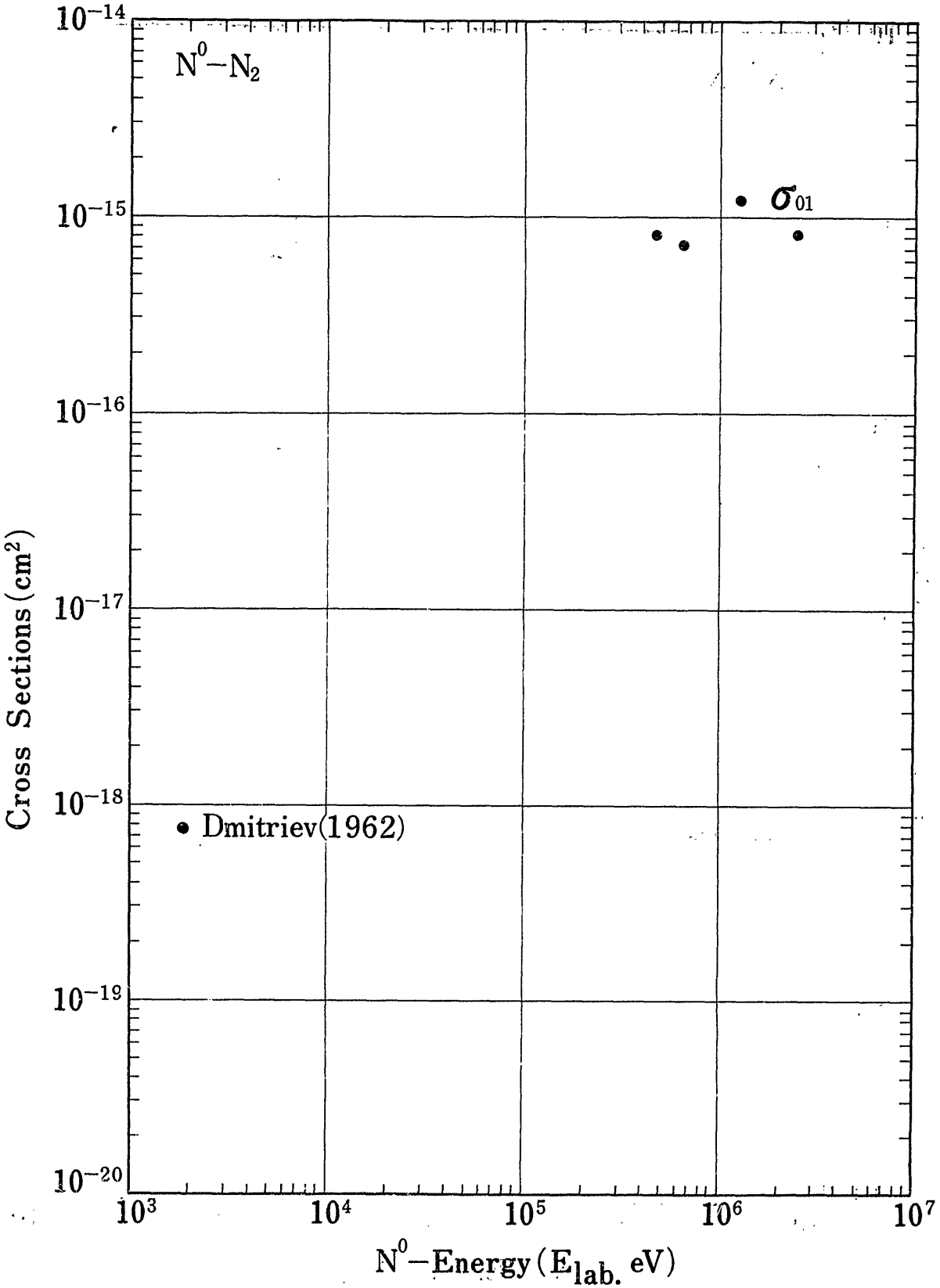


Fig. 21 Charge Changing Cross Sections of N^0 in N_2

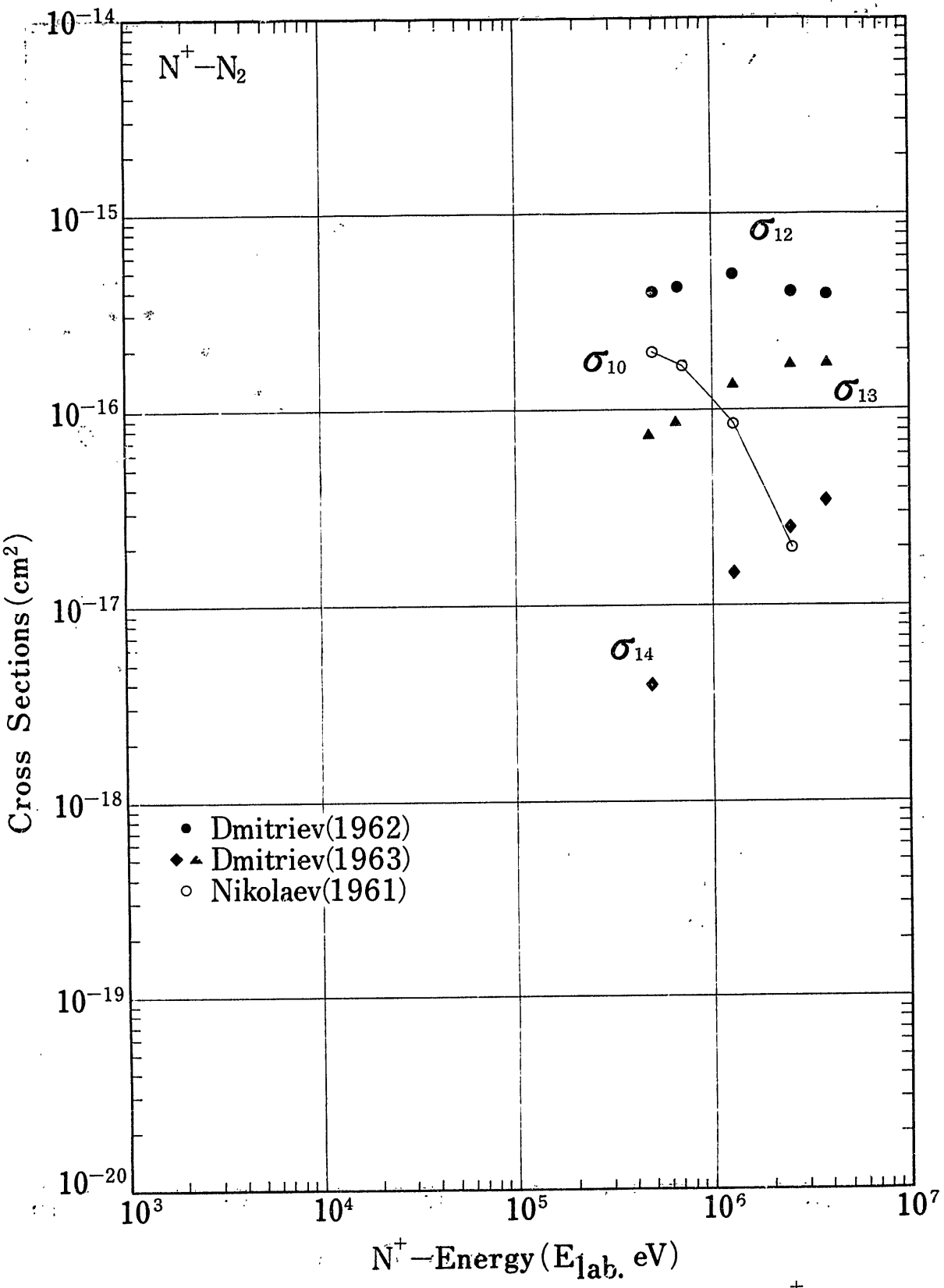


Fig.22 Charge Changing Cross Sections of N^+ in N_2

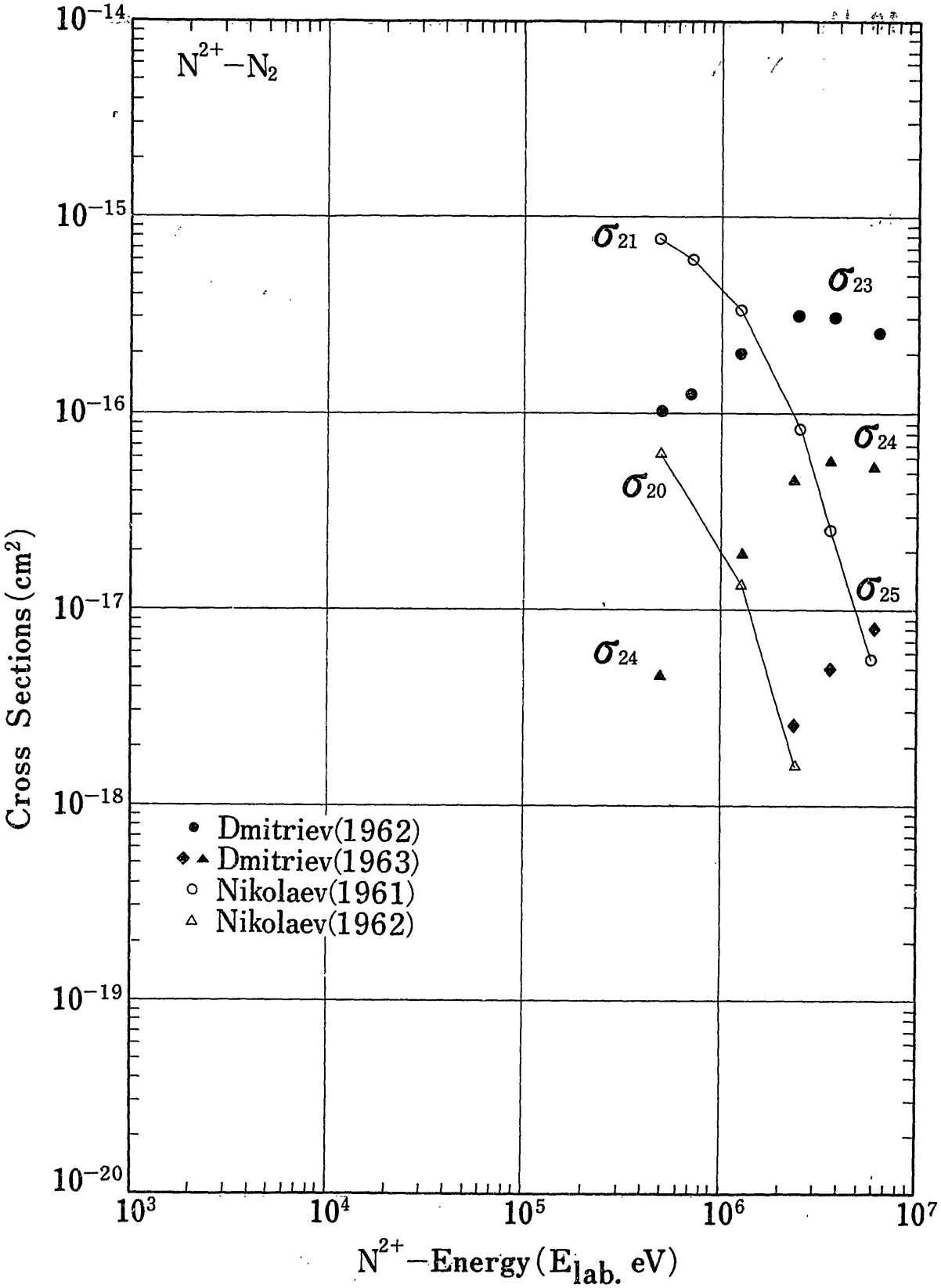


Fig.23 Charge Changing Cross Sections of N^{2+} in N_2

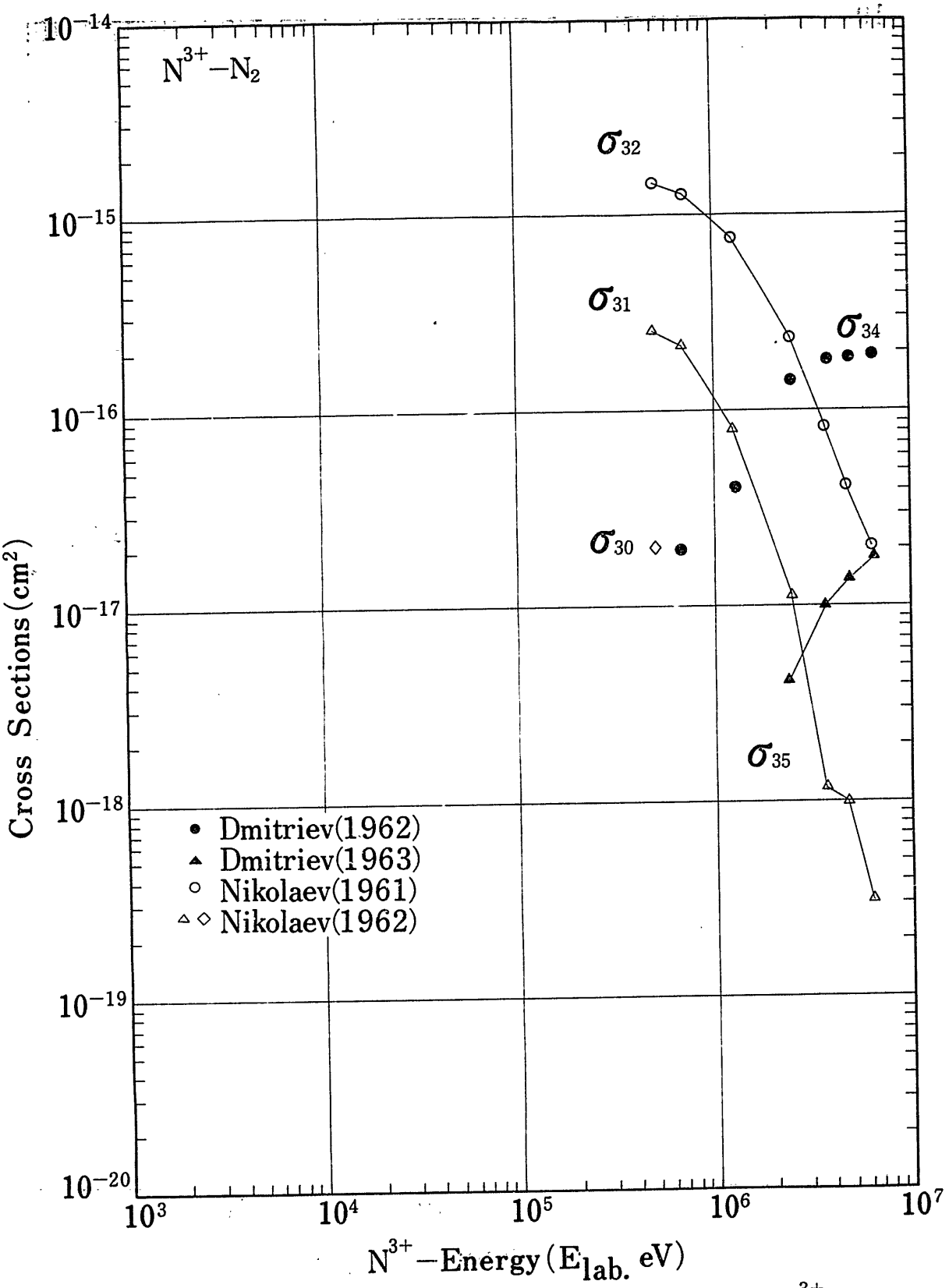


Fig.24 Charge Changing Cross Sections of N^{3+} in N_2

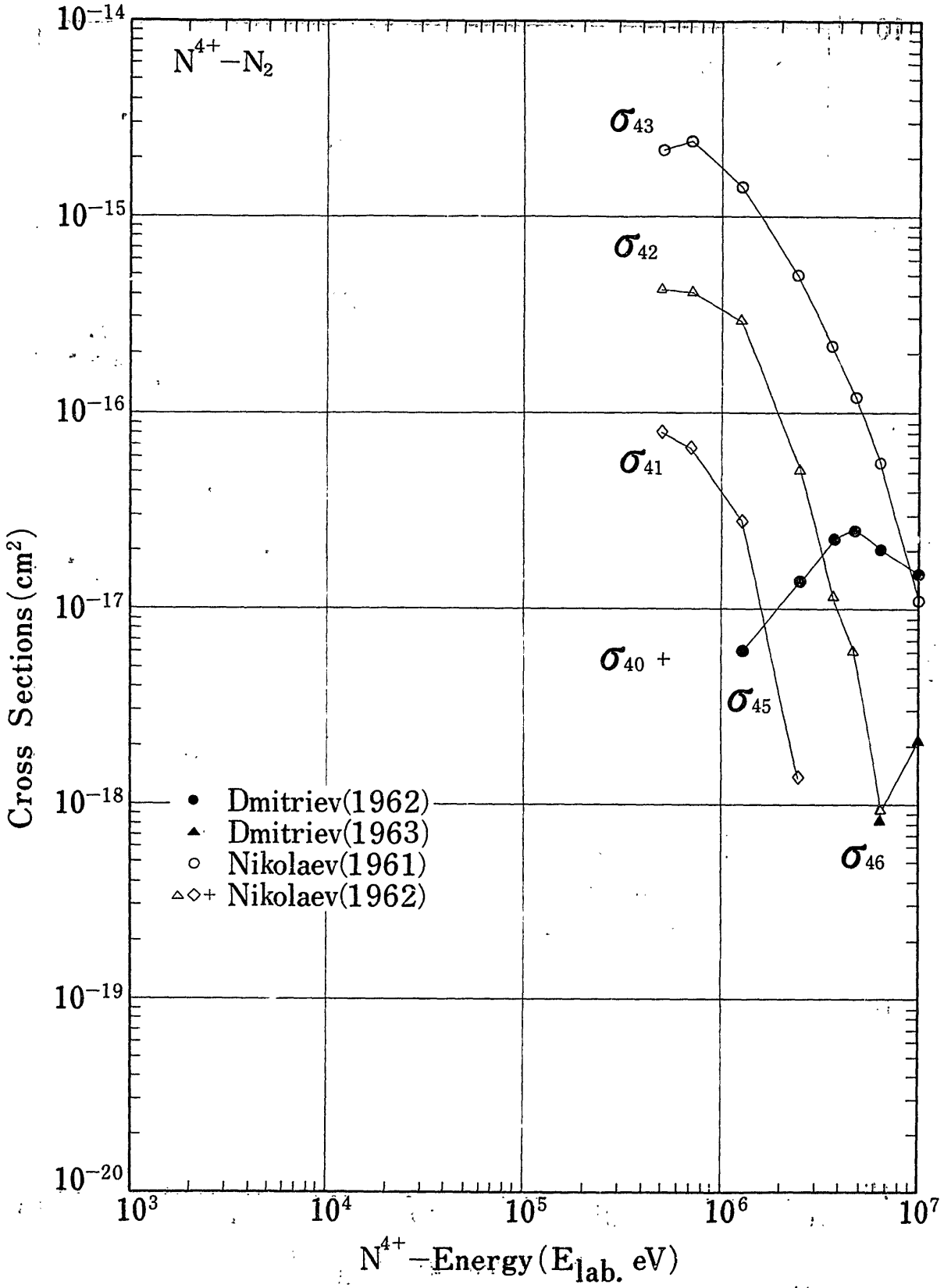


Fig. 25 Charge Changing Cross Sections of N^{4+} in N_2

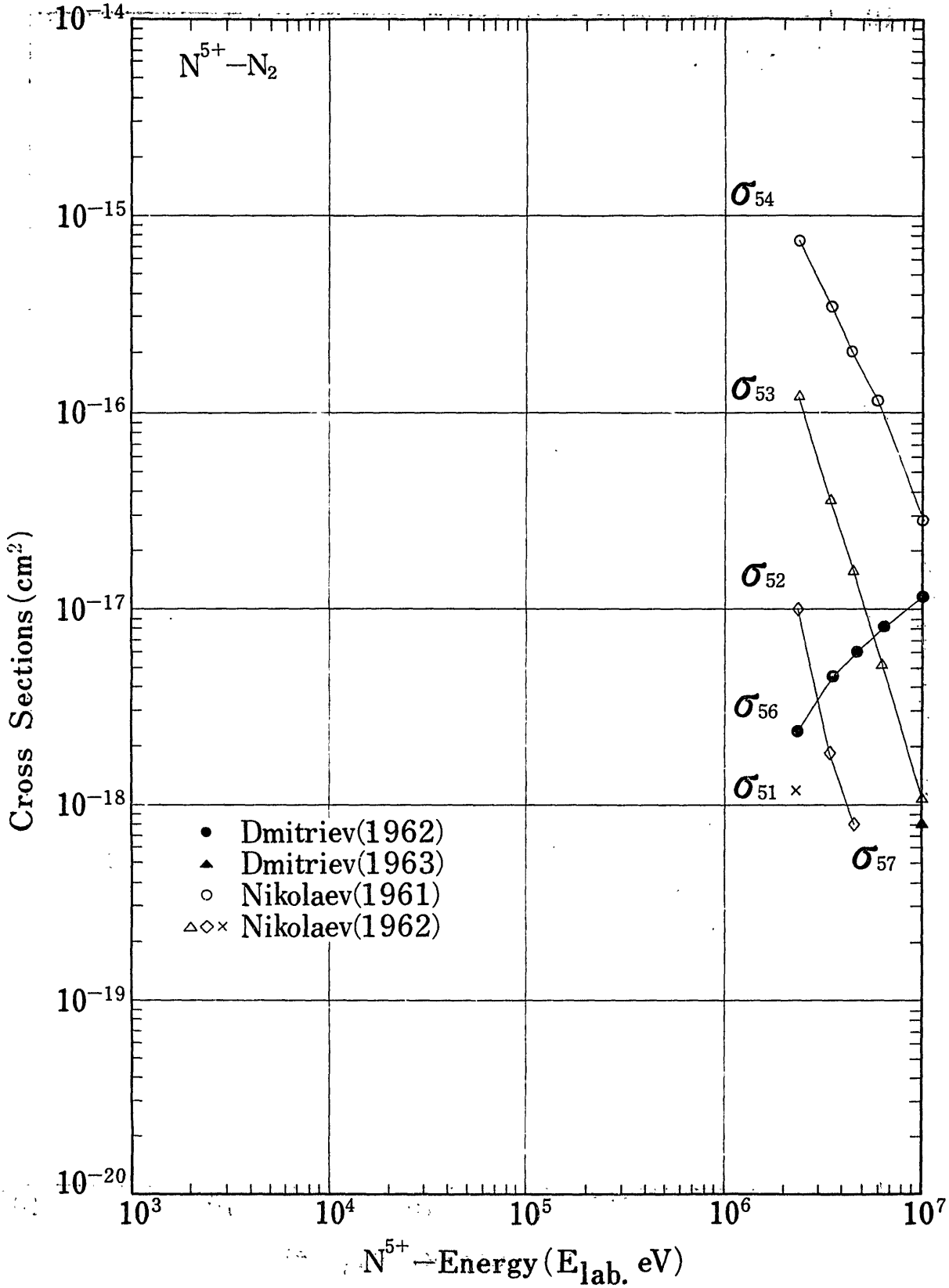


Fig.26 Charge Changing Cross Sections of N^{5+} in N_2

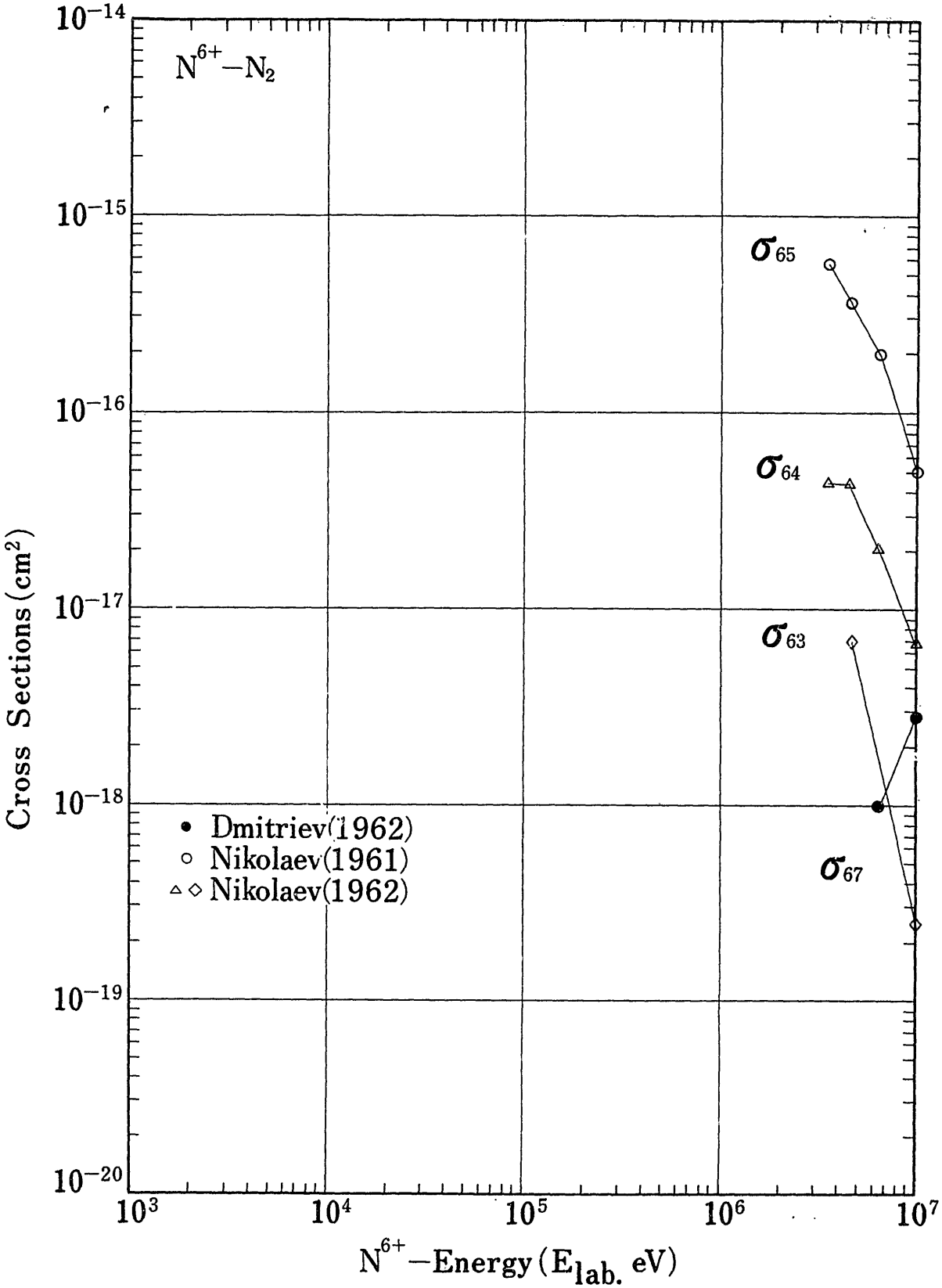


Fig.27 Charge Changing Cross Sections of N^{6+} in N_2

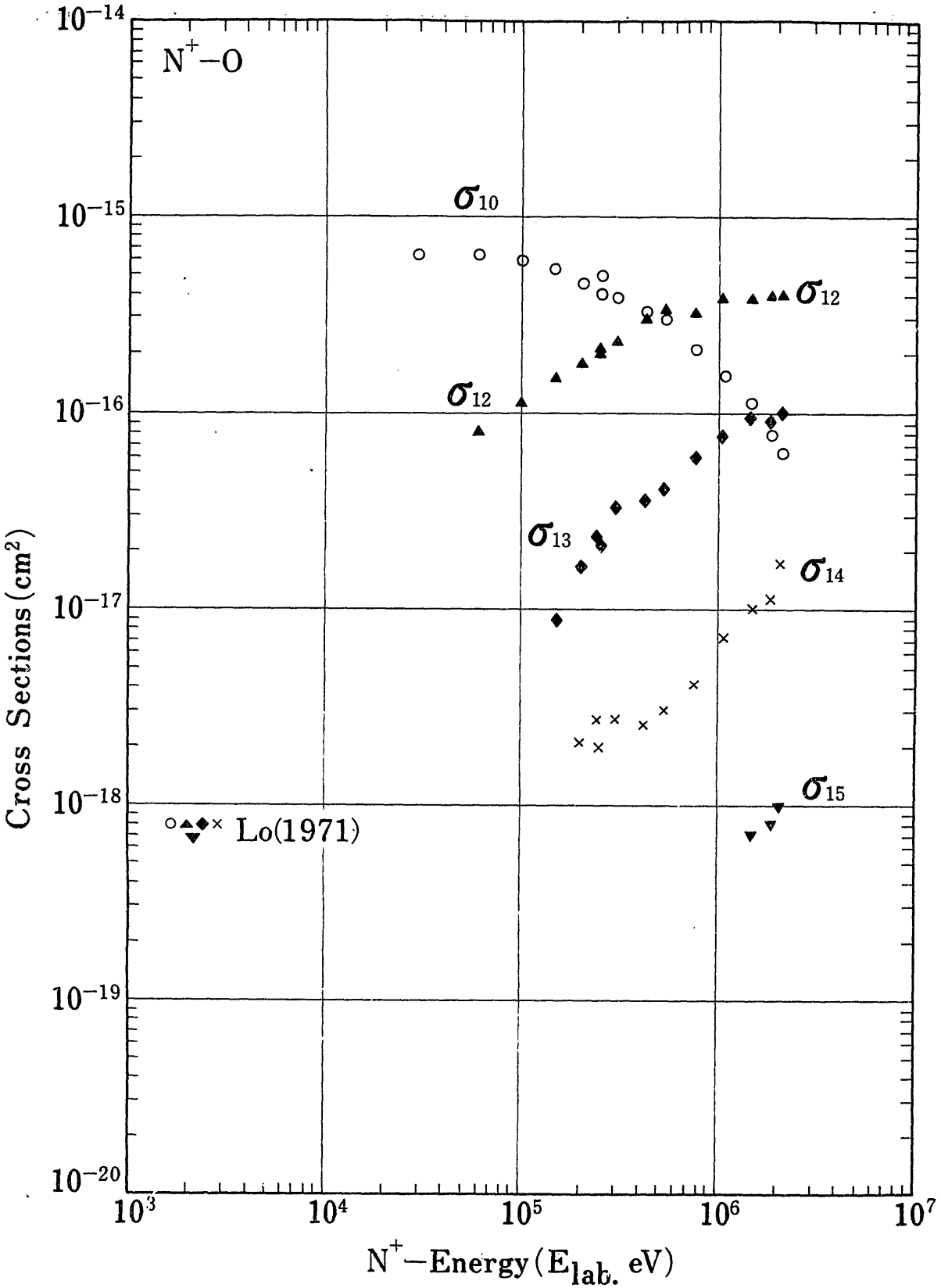


Fig.28 Charge Changing Cross Sections of N^+ in O

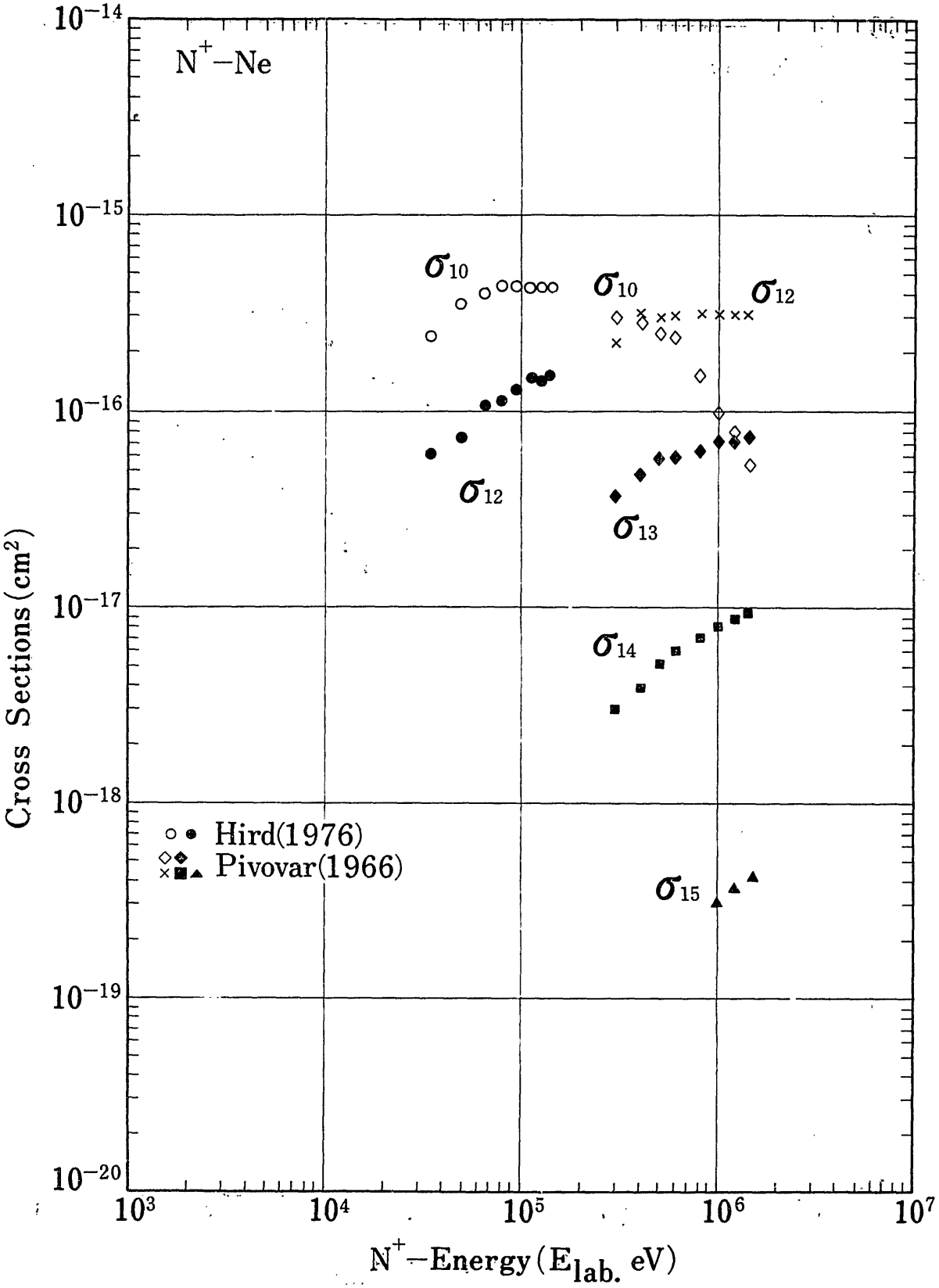


Fig. 29 Charge Changing Cross Sections of N^+ in Ne

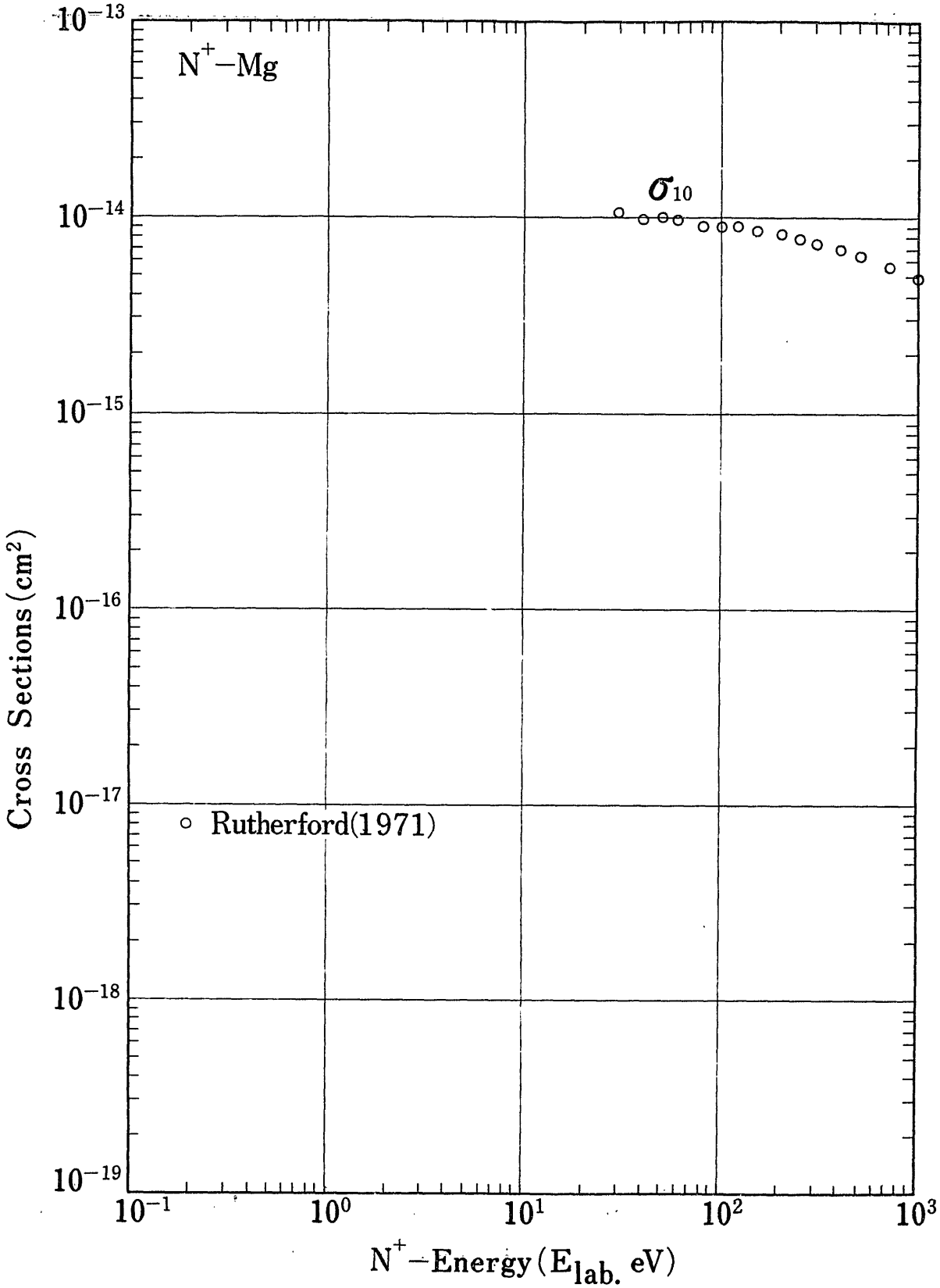


Fig. 30–a Charge Changing Cross Sections of N^+ in Mg

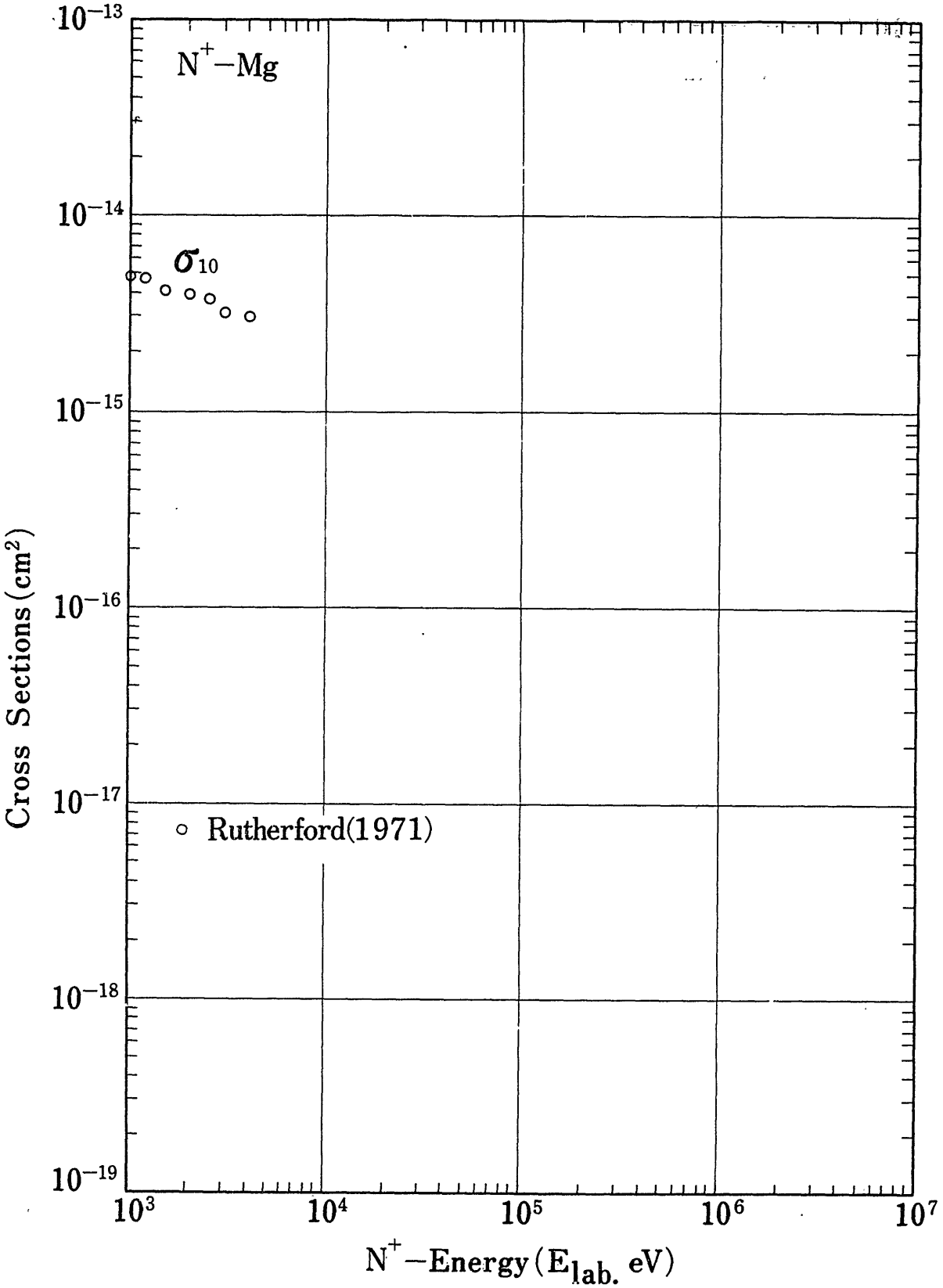


Fig. 30–b Charge Changing Cross Sections of N^+ in Mg

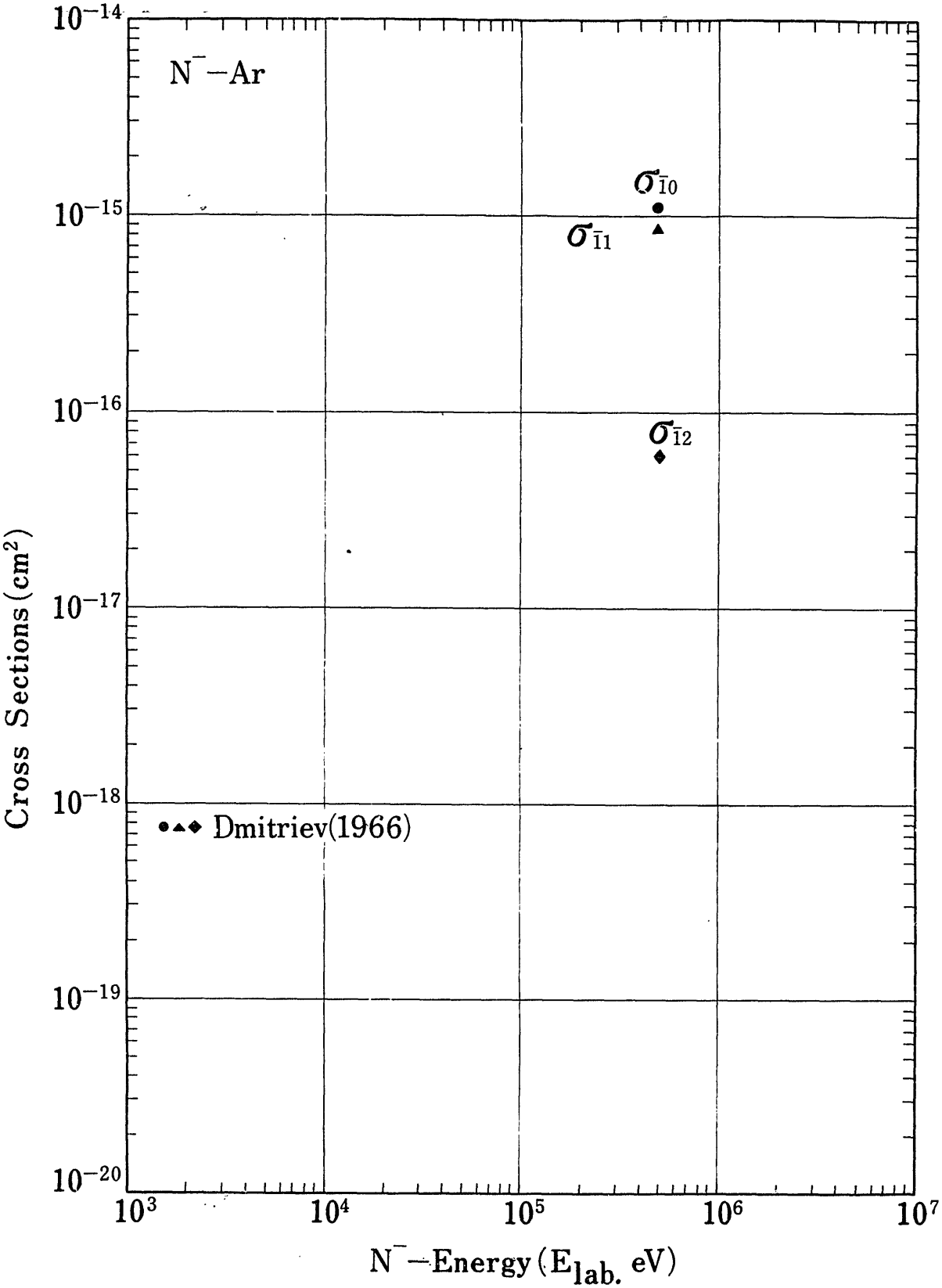


Fig.31 Charge Changing Cross Sections of N^- in Ar

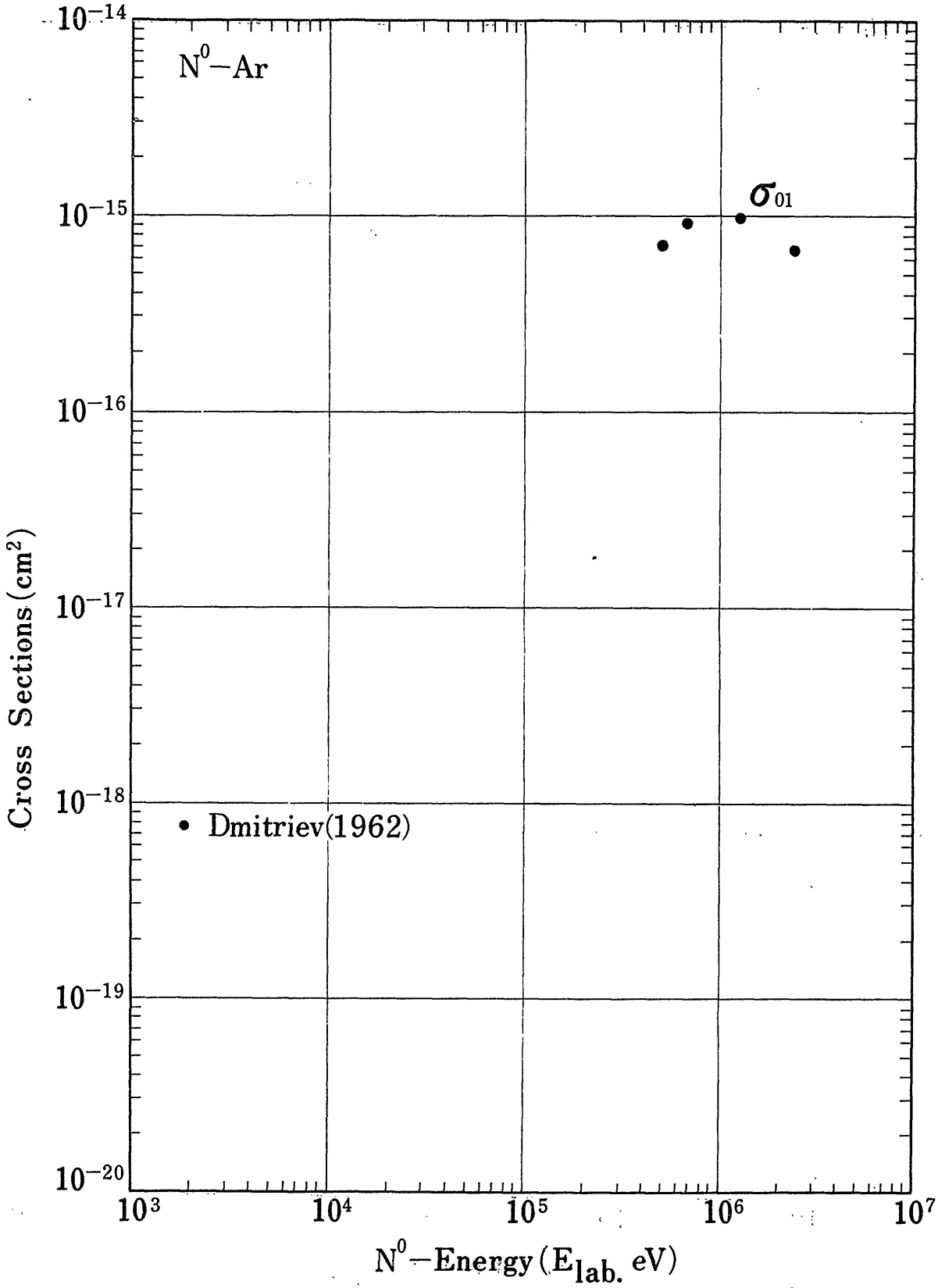


Fig.32 Charge Changing Cross Sections of N^0 in Ar

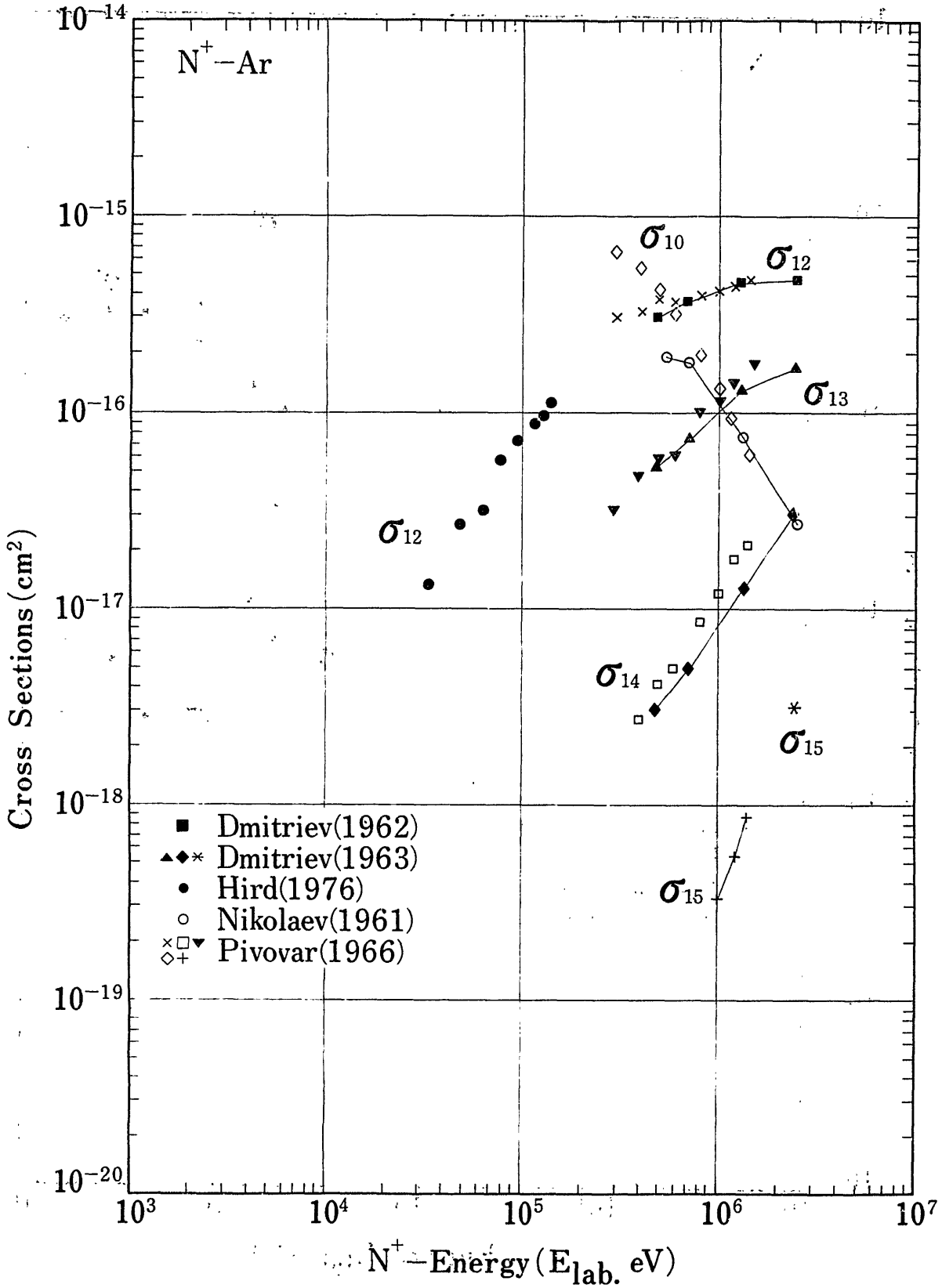


Fig.33 Charge Changing Cross Sections of N^+ in Ar

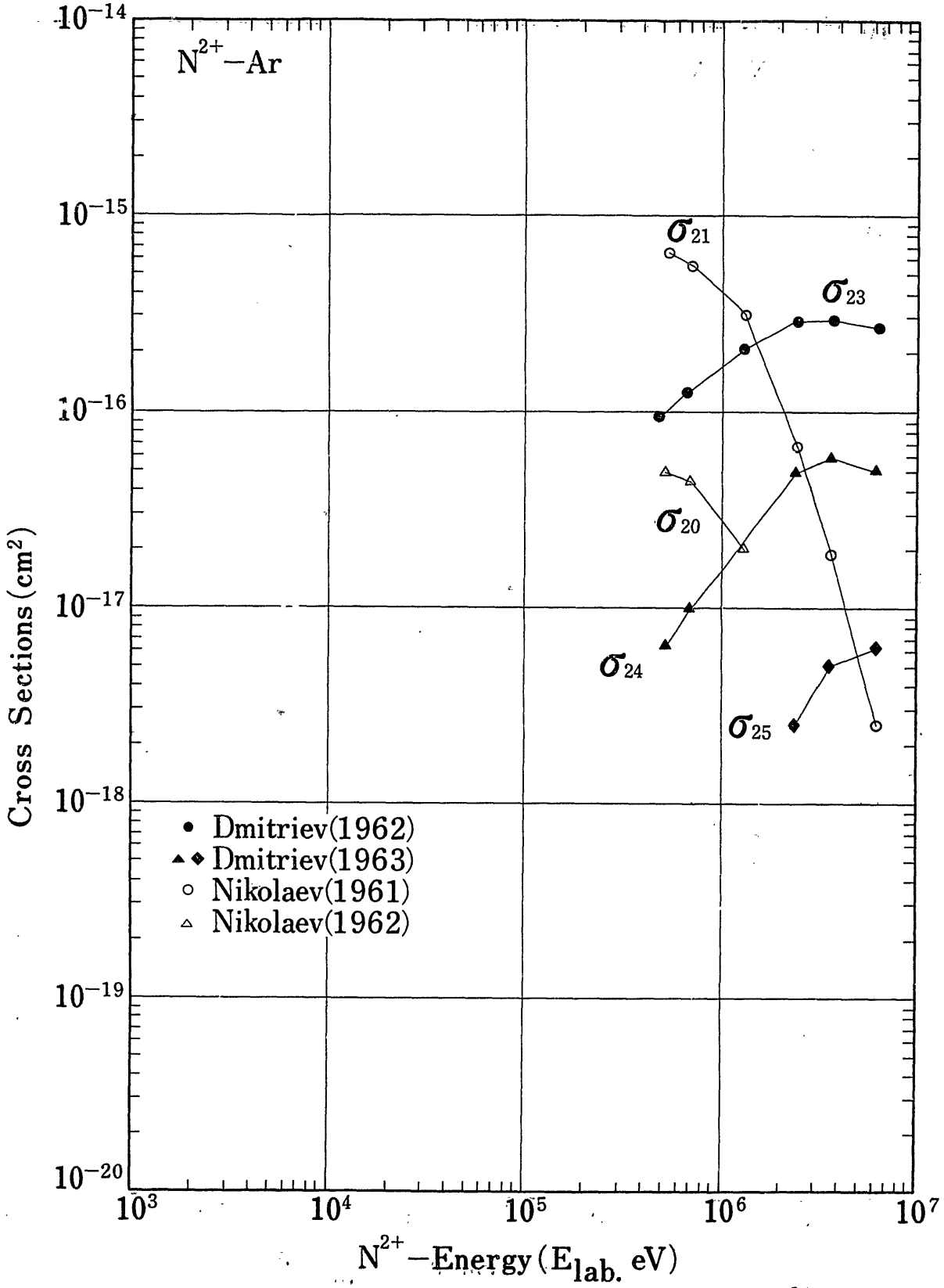


Fig. 34 Charge Changing Cross Sections of N^{2+} in Ar

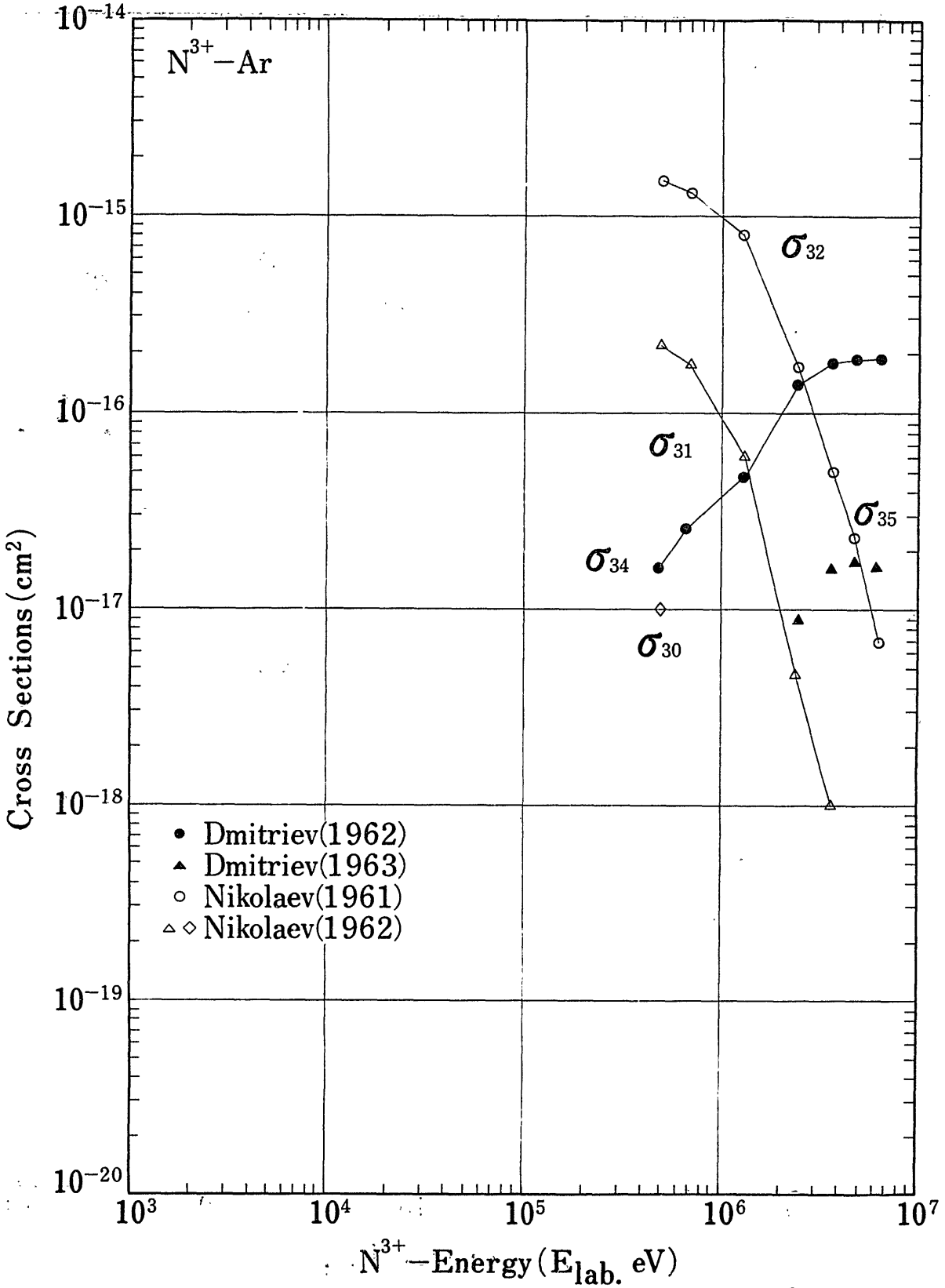


Fig. 35 Charge Changing Cross Sections of N^{3+} in Ar

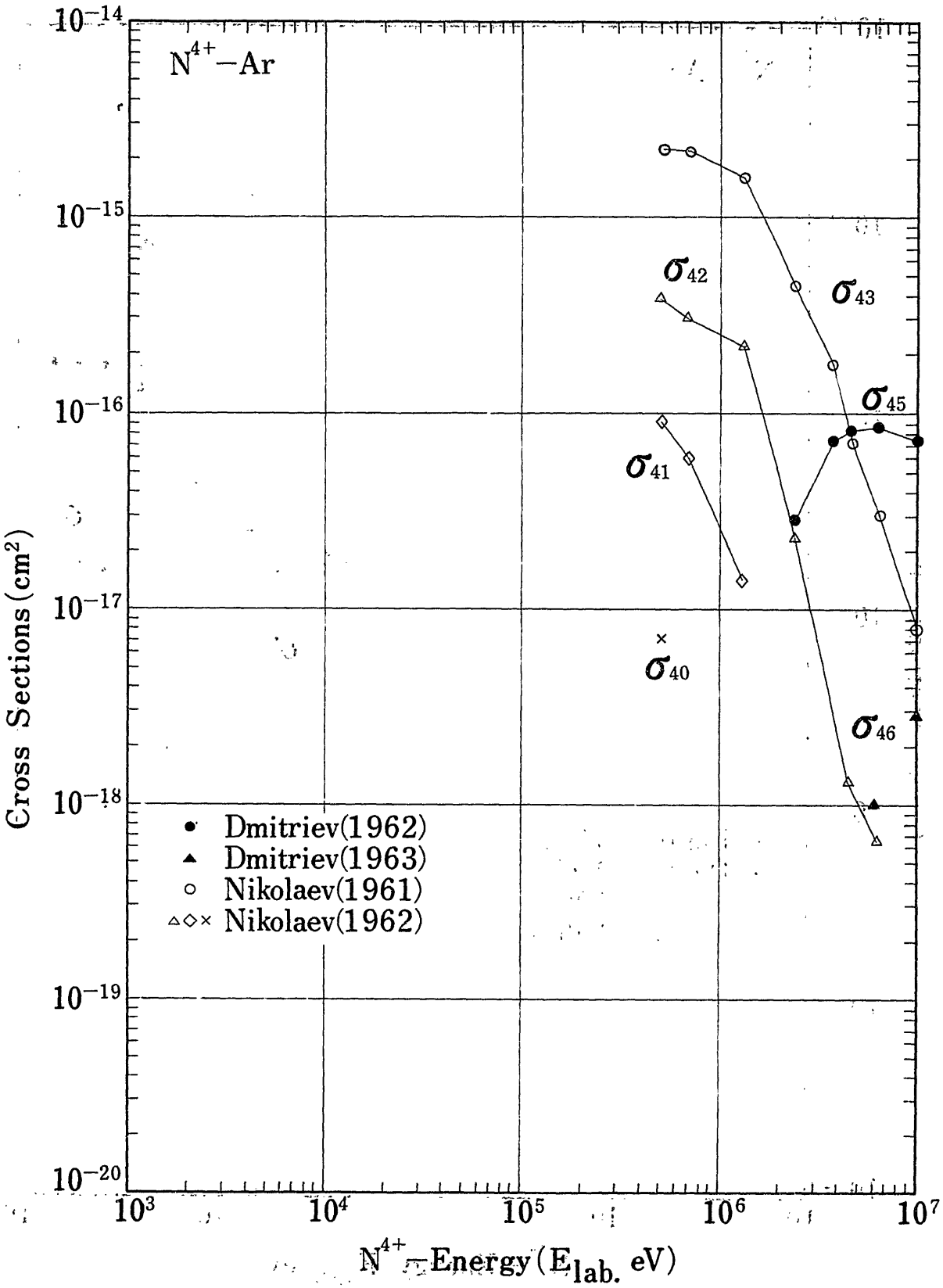


Fig.36 Charge-Changing Cross Sections of N^{4+} in Ar

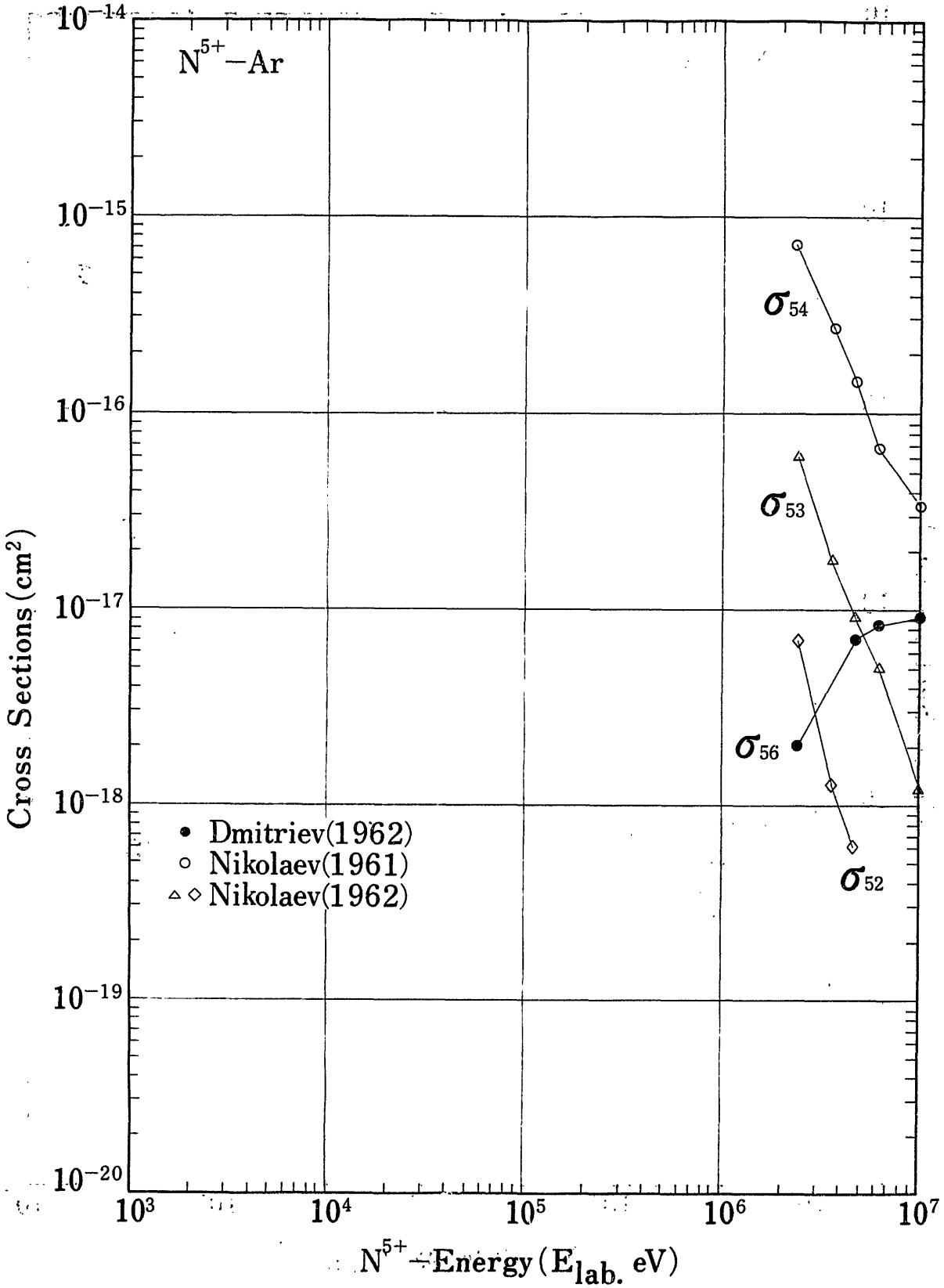


Fig. 37 Charge Changing Cross Sections of N^{5+} in Ar

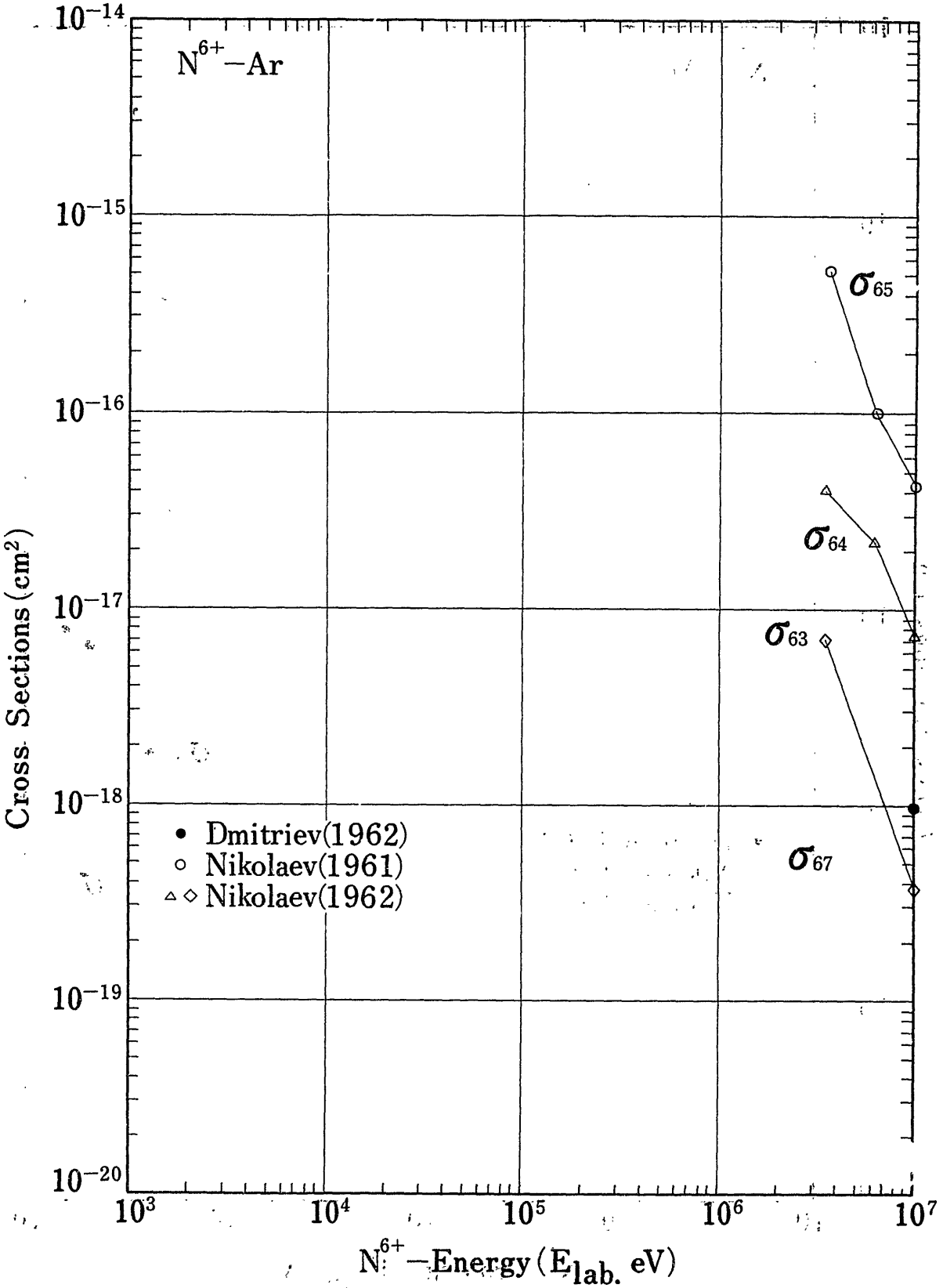


Fig.38 Charge Changing Cross Sections of N^{6+} in Ar

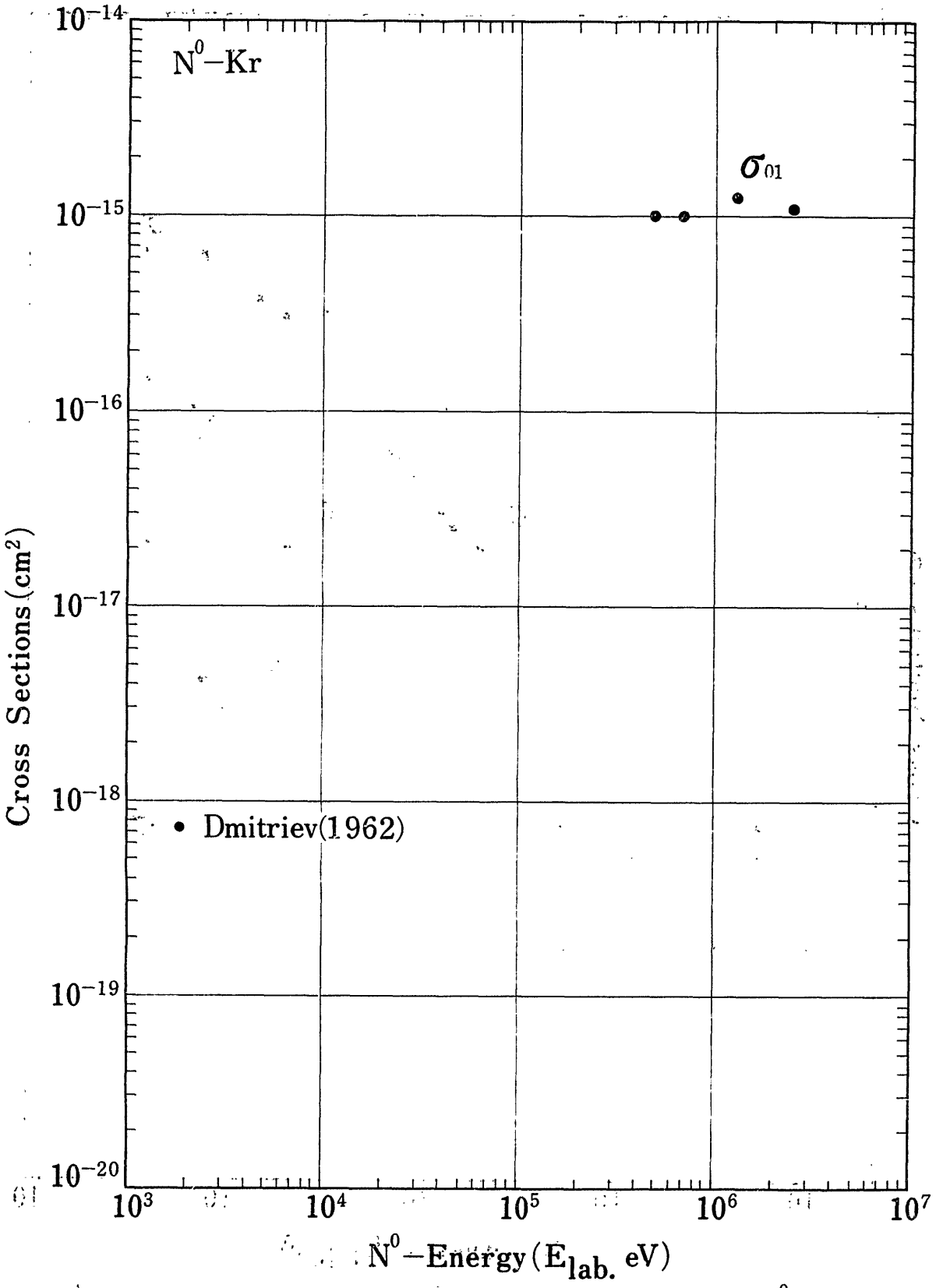


Fig. 39 Charge Changing Cross Sections of N^0 in Kr

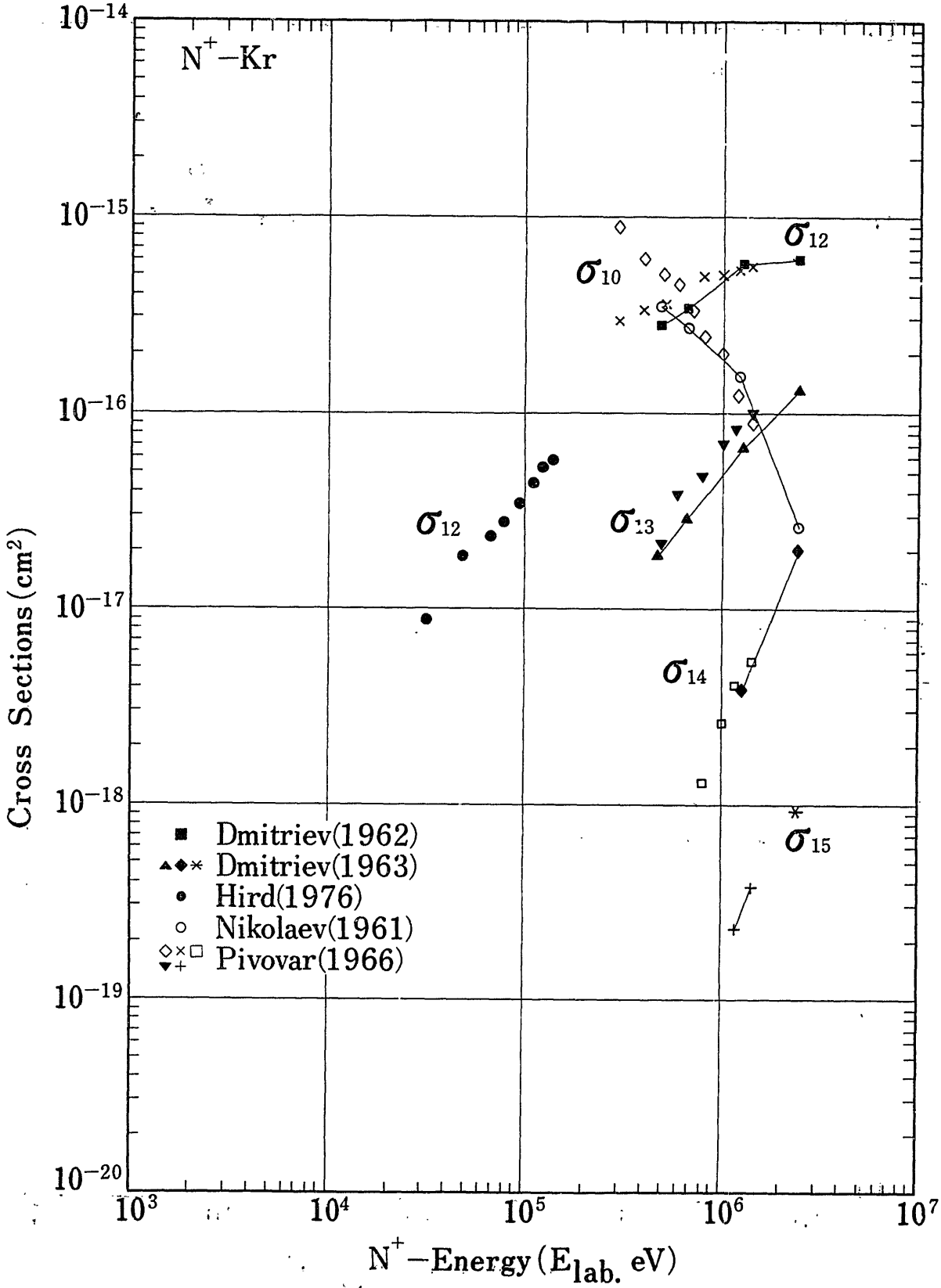


Fig.40 Charge Changing Cross Sections of N^+ in Kr

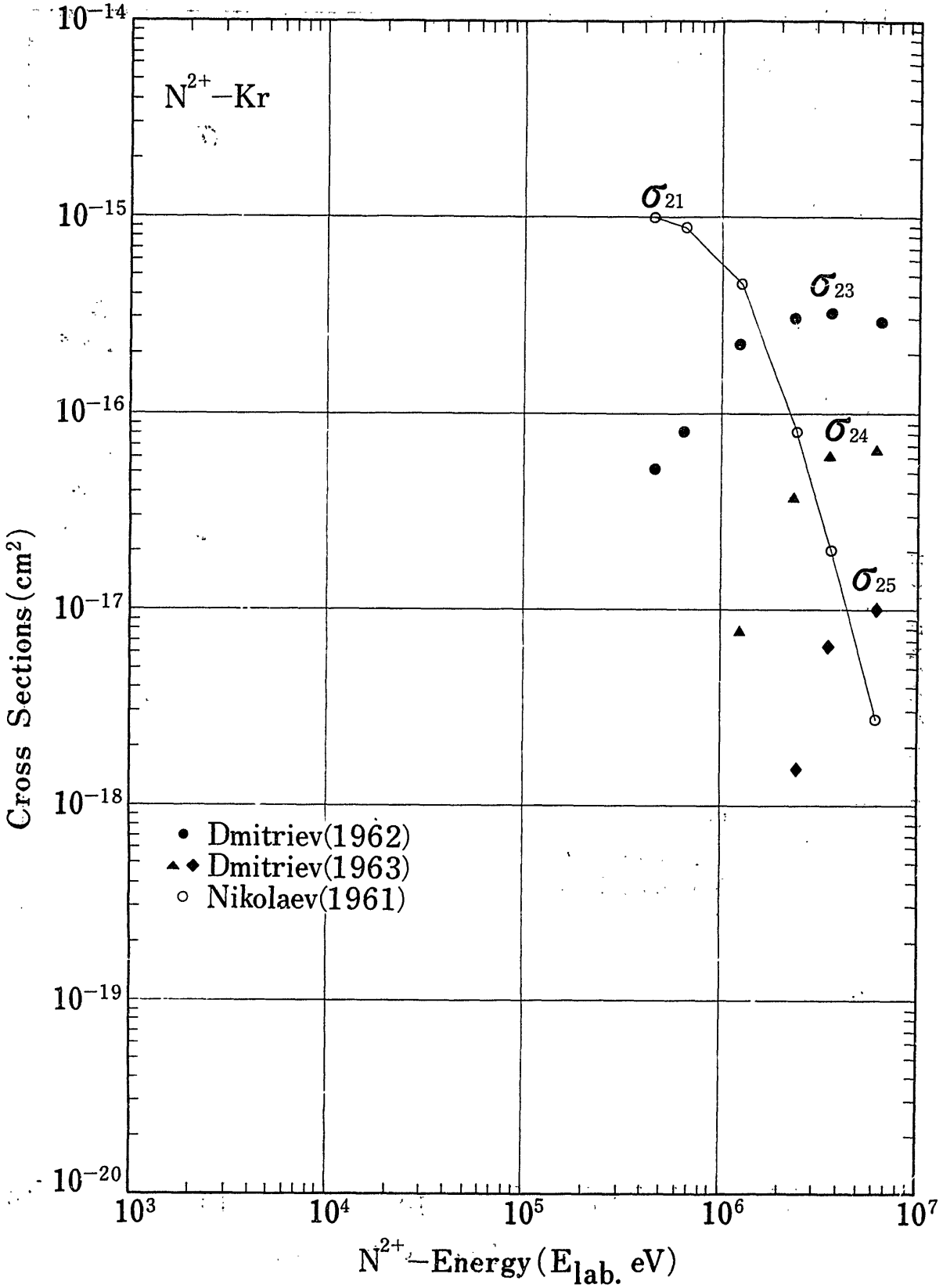


Fig. 41 Charge Changing Cross Sections of N^{2+} in Kr

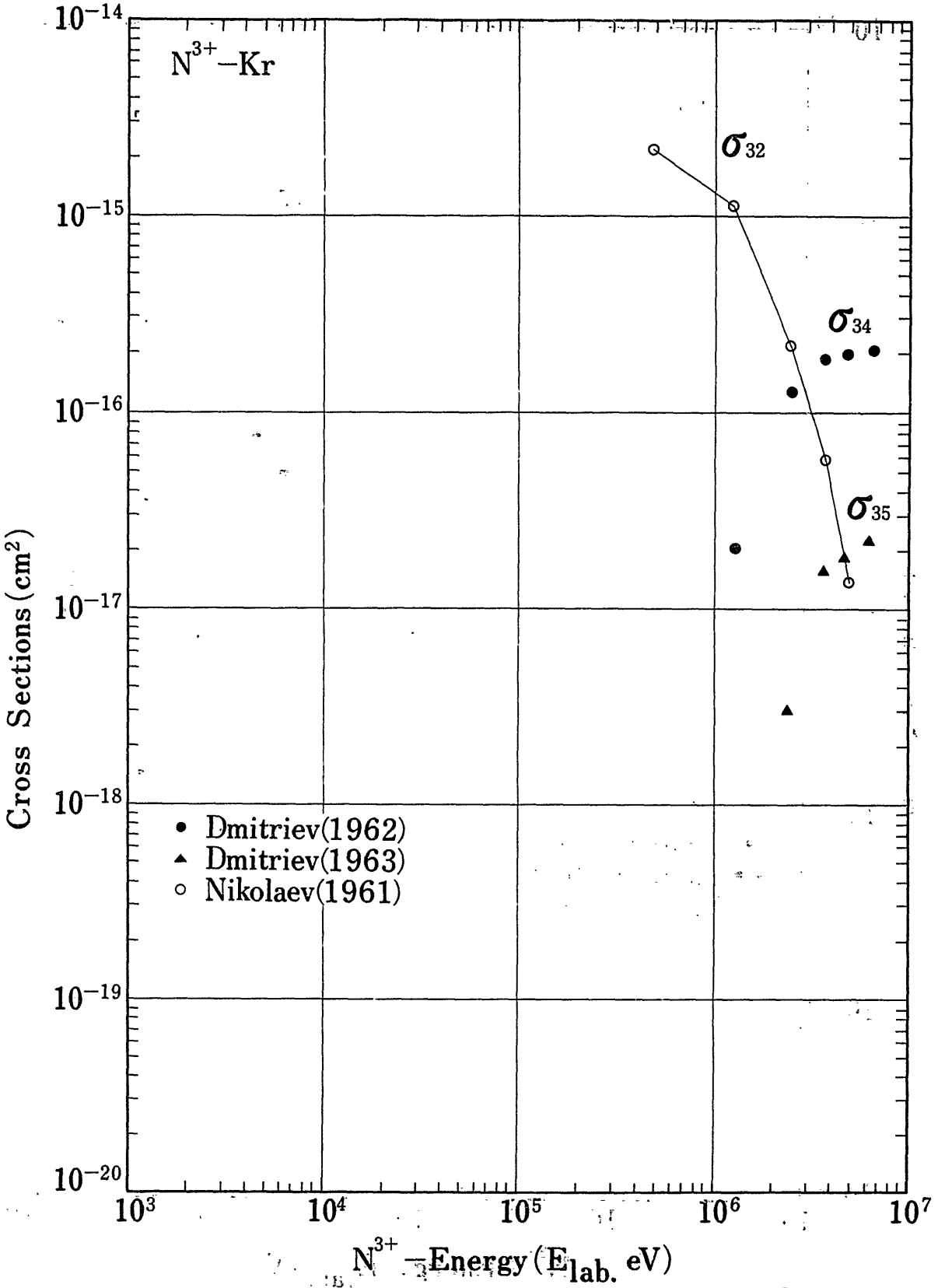


Fig.42 Charge-Changing Cross Sections of N^{3+} in Kr

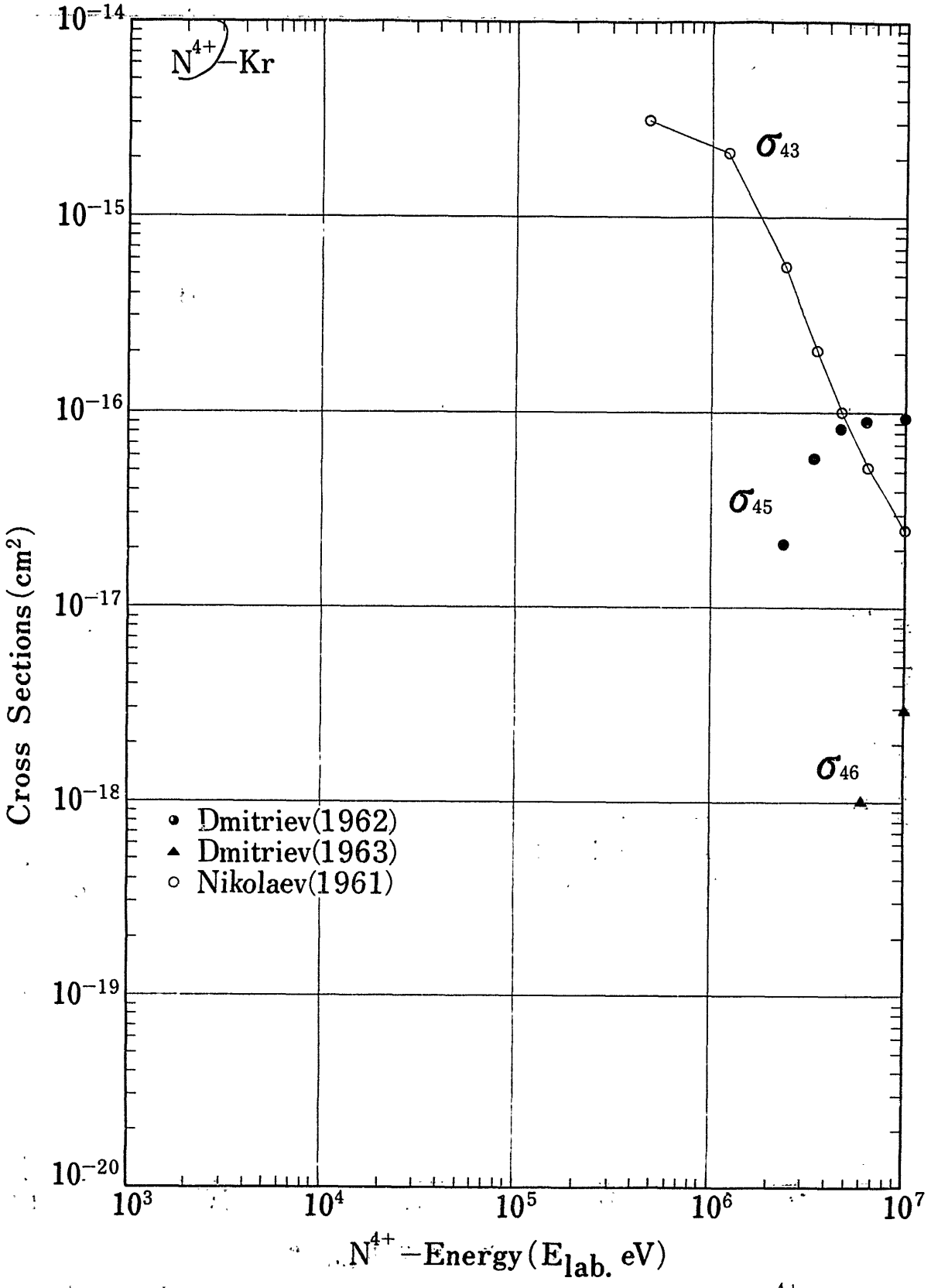


Fig. 43 Charge Changing Cross Sections of N^{4+} in Kr

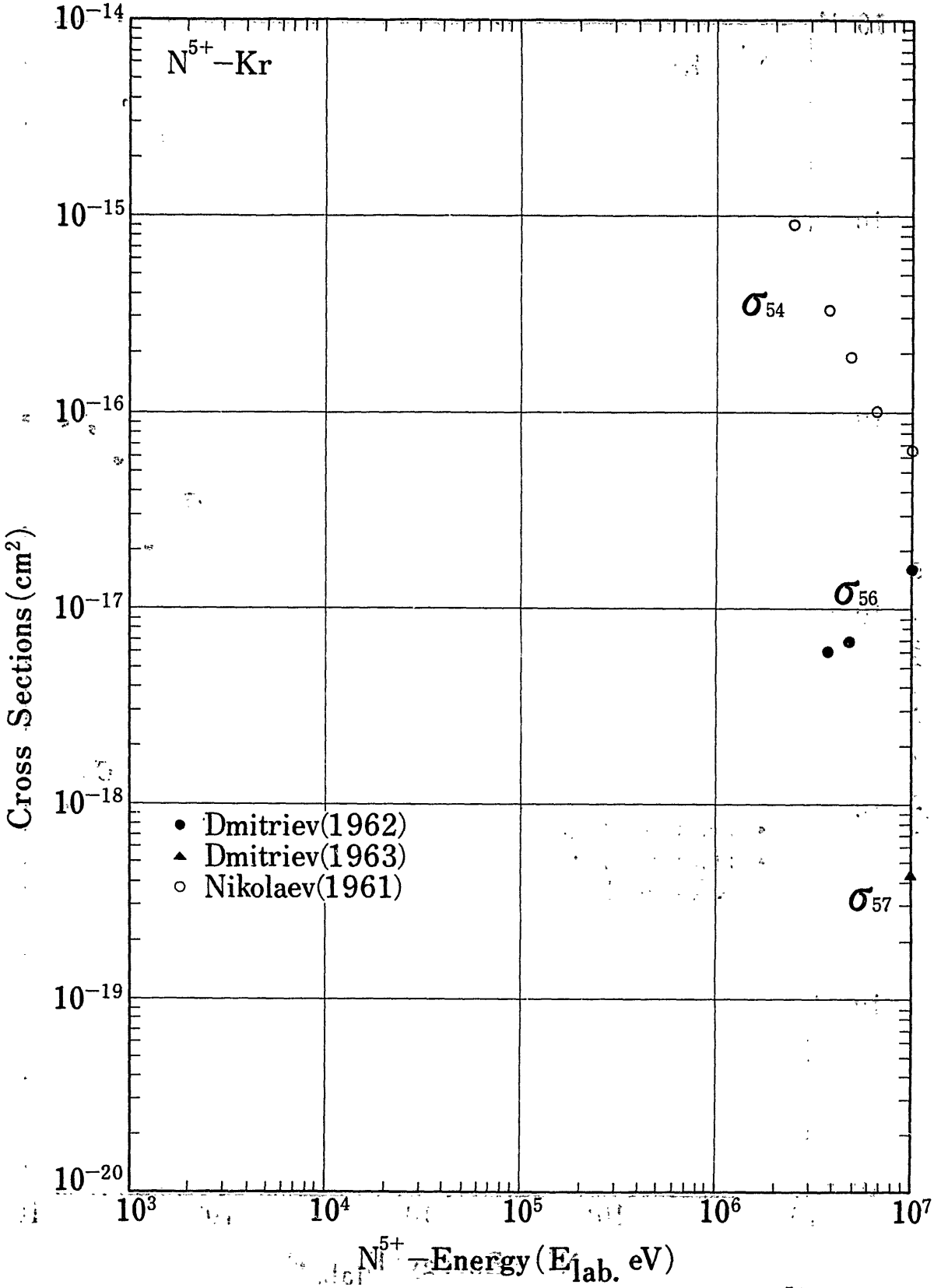


Fig. 44 Charge Changing Cross Sections of N^{5+} in Kr

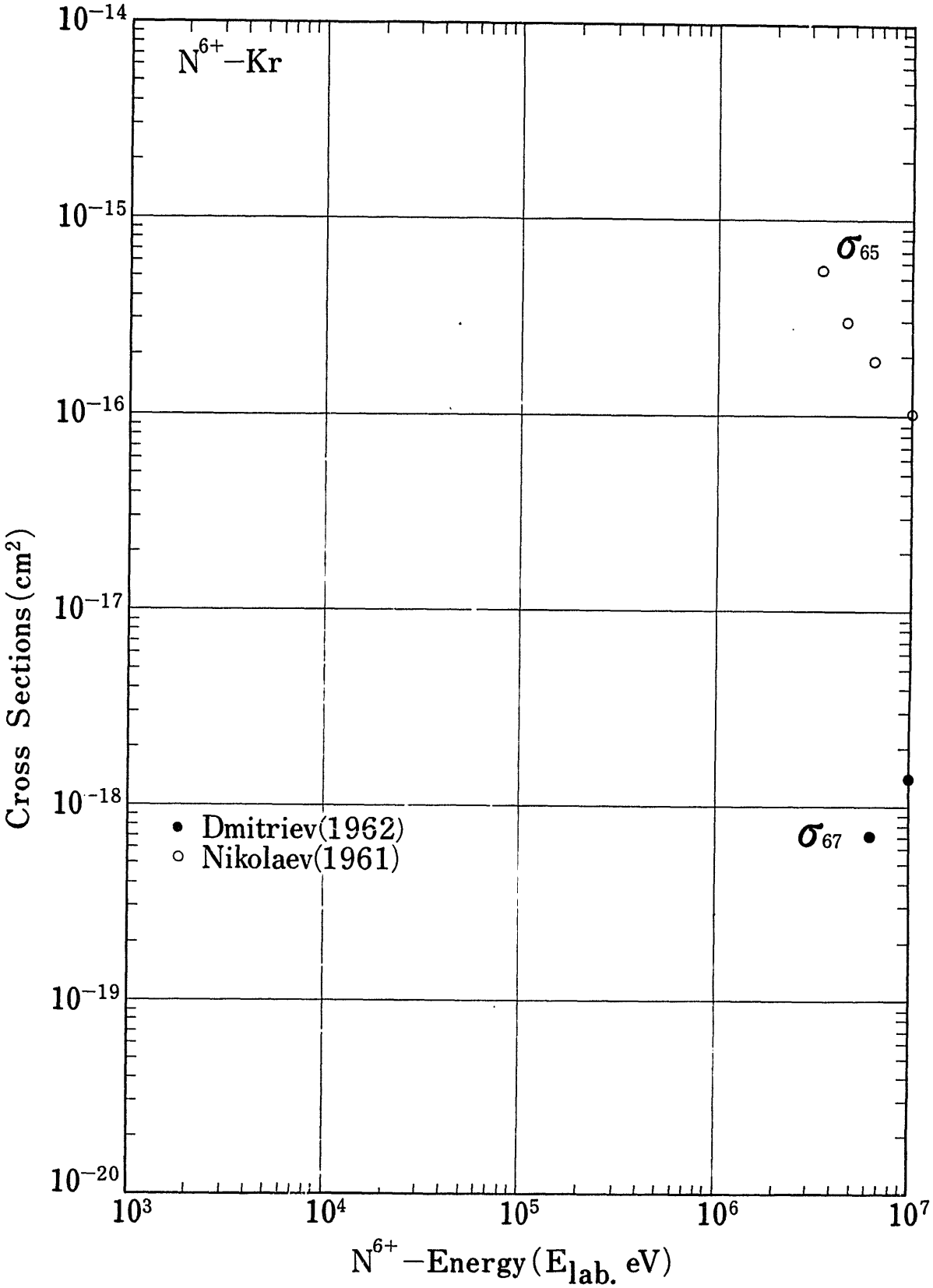
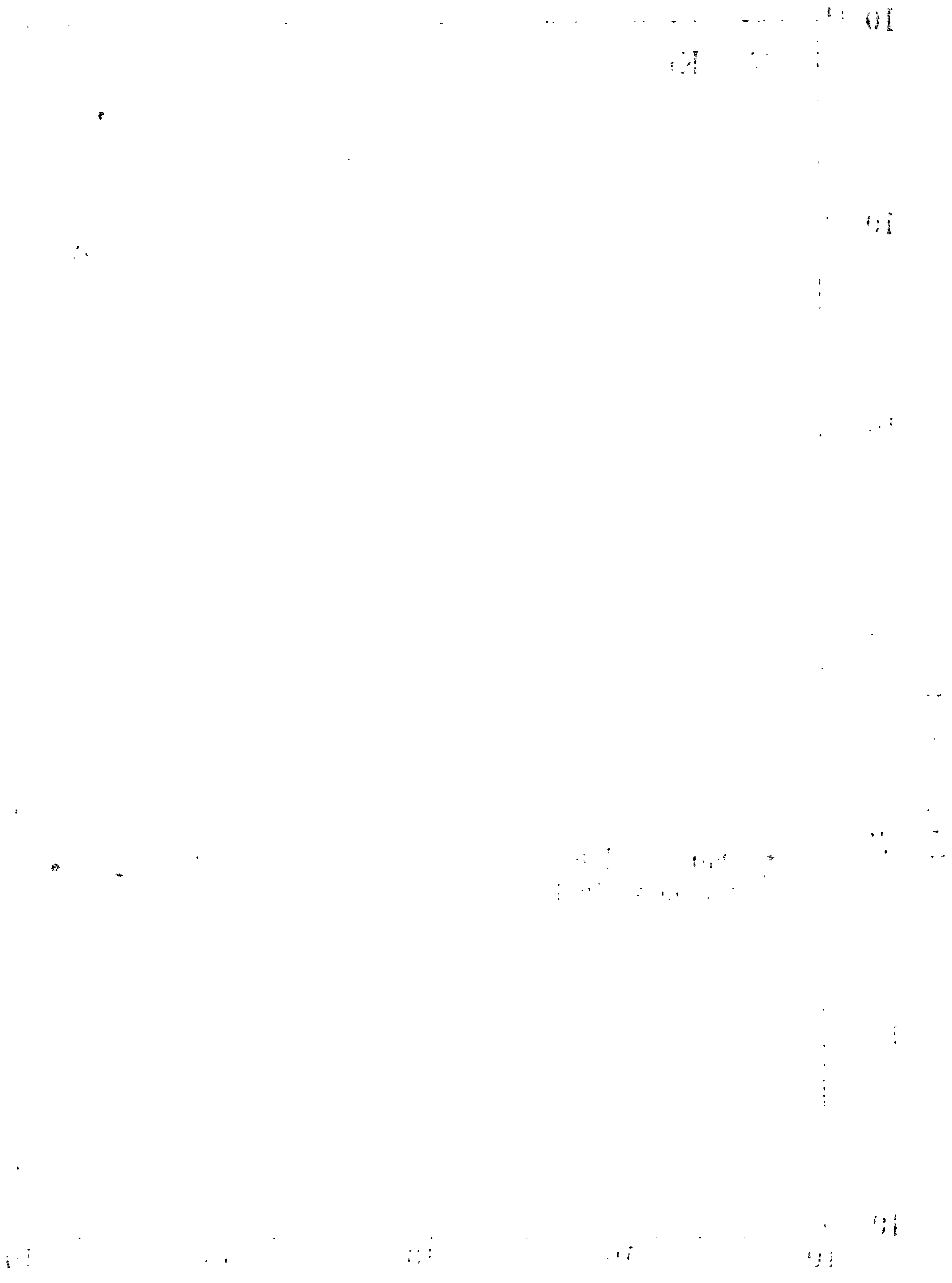


Fig.45 Charge Changing Cross Sections of N^{6+} in Kr



N Energy

Fig.45 Charge Changing Cross Sections of N

Charge Changing Cross Sections of Oxygen Atoms and Ions, Z=8.

I. Lists of Reference

II. Tables of Experimental Data

A) Electron Capture Cross Sections

B) Electron Loss Cross Sections

C) Cross Sections of Ionization, Slow ions Productions and Electron productions

III. Graphs of Charge Changing Cross Sections

I. References for Experimental Data of O (Z=8).

1. T.L.Bailey and P.Mahadevan, J. Chem. Phys. 52, 179 (1970)

2. R.A.Bennett, J.T.Mosely and J.R.Peterson, J. Chem. Phys. 62, 2223 (1975)

3. F.W.Bingham, Phys. Rev. 182, 180 (1969)

4. F.W.Bingham, Phys. Rev. A 2, 1365 (1970)

5. D.K.Bohme, P.P.Ong, J.B.Hasted and L.R.Megill, Planet. Space Sci. 15, 1777 (1967)

6. R.T.Brackmann and W.L.Fite, AFWL-TR-68-96 (1968)

7. R.T.Brackmann, W.L.Fite and H.H.Lo, AFWL-TR-70-9 (1970)

8. D.Burch, H.Wieman and W.B.Ingalls, Proc. 8th ICPEAC, Beograd, (1973) p.683

9. B.Cobic, M.Vujovic and M.Matic, Fizika. (Yugoslavia) 2, 221 (1970)

10. B.Cobic, M.Vujovic and M.Matic, J. Phys. B 3, 374 (1970)

11. M.H.Copsey, D.Smith and J.Sayers, Planet. Space Sci. 14, 1047 (1966)

12. D.H.Crandall, Proc. 9th ICPEAC, Seattle (1975) p.190

13. D.H.Crandall, M.L.Mallory and D.C.Kocher, Phys. Rev. A 15, 61 (1977)

14. D.H.Crandall, Phys. Rev. A 16, 958 (1977)

15. S.Datz, B.R.Appleton, J.A.Biggerstaff, H.F.Krause, C.D.Moak, T.S.Noggle and R.H.Ritchie, Proc. 9th ICPEAC, Seattle (1975) p.325

16. G.I.Dimov and G.V.Roslyakov, Sov. Phys. Tech. Phys. 17, 90 (1972)

17. I.S.Dmitriev, V.S.Nikolaev, L.N.Fateeva and Y.A. Teplova, Sov. Phys. JETP 15, 11 (1962)

18. I.S.Dmitriev, V.S.Nikolaev, L.N.Fateeva and Y.A. Teplova, Sov. Phys. 16, 259 (1963)

19. I.S.Dmitriev, V.S.Nikolaev, Ya.A.Teplova, B.M.Popov and L.I.Vinogradova, Sov. Phys. JETP 23, 832 (1966)

20. I.S.Dmitriev, V.S.Nikolaev, Ya.A.Teplova and B.A. Prigodin, Proc. 6th ICPEAC,Cambridge, (1969) p.460

21. I.S.Dmitriev, Ya.A.Teplova and V.S.Nikolaev, Sov. Phys. JETP 34, 723 (1972)

22. D.B.Dunking, F.C.Fehsenfeld, A.L.Schmeltekopf and E.E. Ferguson, J. Chem. Phys. 49, 1365 (1968)

23. B.A.Dyachkov and V.I.Zinenko, Sov. Phys. Tech. Phys. 18, 1087 (1974)

24. A.K.Edwards, Phys. Rev. A 12, 1830 (1975)

25. V.F.Elaev and O.P.Semenova, Izv. VUZ. Fiz. 1, 19 (1975)

26. E.E.Ferguson, Rev. Geophys. 5, 305 (1967)

27. E.E.Ferguson, D.K.Bohme, F.C.Fehsenfeld and D.B. Dunkin, J. Chem. Phys. 49, 1365 (1968)

28. E.E.Ferguson, Ann. Geophys. 28, 389 (1972)

29. W.L.Fite, R.F.Stebbings, D.G.Hummer and R.T. Brackmann, Phys. Rev. 119, 663 (1960)

30. W.L.Fite, A.C.H.Smith and R.F.Stebbings, Proc. Roy. Soc. A 268, 527 (1968)

31. W.L.Fite, J.D.Garcia, E.Gerjuoy and J.A.Pedan, AFWL-TR-69-26 (1969)

32. Ya.M.Fogel' and L.I.Krupnik, Sov. Phys. JETP 2, 252 (1956)

33. Ya.M.Fogel', R.V.Mitin and A.G.Koval', Sov. Phys. JETP 4, 359 (1957)

34. Ya.M.Fogel', L.I.Krupnik, A.G.Koval' and R.P. Slabospitskii, Sov. Phys. Tech. Phys. 2, 902 (1957)

35. Ya.M.Fogel', V.A.Ankudinov, D.V.Pilipenko and N.V. Topolia, Sov. Phys. JETP 7, 400 (1958)

36. Ya.M.Fogel', V.A.Ankudinov and D.V.Pilipenko, Sov. Phys. JETP 8, 601 (1959)

37. Ya.M.Fogel', A.G.Koval' and Yu.Z.Levchenko, Sov. Phys. JETP 11, 760 (1960)

38. Ya.M.Fogel', Usp. Fiz. Nauk. 69, 243 (1960)

39. C.F.Giese, Advan. Chem. Ser. 58, 20 (1966)

40. P.D.Goldan, A.L.Schmeltekopf, F.C.Fehsenfeld, H.I. Schiff and E.E.Ferguson, J. Chem. Phys. 44, 4095 (1966)

41. J.B.Hasted, Proc. Roy. Soc. A 212, 235 (1952)

42. J.B.Hasted, Proc. Roy. Soc. A 205, 421 (1951)

43. J.B.Hasted and R.A.Smith, Proc. Roy. Soc. A 235, 349 (1956)

44. J.B.Hasted, S.M.Iqbal and M.M.Yousaf, Proc. 7th ICPEAC, Amsterdam, (1971) p.126

45. J.B.Hasted, S.M.Iqbal and M.M.Yousaf, J. Phys. B 4, 343 (1971)

46. D.G.Hummer, R.F.Stebbings, W.L.Fite and L.M.Branscomb, Phys. Rev. 119, 668 (1960)

47. R.N.Il'in and E.S.Solov'ev, Sov. Phys. Tech. Phys. 6, 491 (1961)

48. R.Johnsen, H.L.Brown and M.A.Biondi, J. Chem. Phys. 52, 5080 (1970)

49. T.Jorgensen, C.E.Kuyatt, W.W.Lang, D.C.Lorents and C.A.Sautter, Phys. Rev. 140A, 1481 (1965)

50. Y.Kaneko and N.Kobayashi, J. Phys. Soc. Japan 36, 1649 (1974)

51. E.J.Knystantas, Q.C.Kessel, R.DelBoca and H.C.Hayden, Phys. Rev. A 1, 825 (1970)

52. R.G.Kosmider and J.B.Hasted, J. Phys. B 8, 273 (1975)

53. H.H.Lo, L.Kurzweg, R.T.Brackmann and W.L.Fite, Proc. 6th ICPEAC, Cambridge, (1969) p.705

54. H.H.Lo, L.Kurzweg, R.T.Brackmann and W.L.Fite, Phys. Rev. A 4, 1462 (1971)

55. J.R.Macdonald and F.W.Martin, Proc. 6th ICPEAC Cambridge, (1969) p.702

56. J.R.Macdonald and F.W.Martin, Phys. Rev. A 4, 1965 (1971)

57. F.W.Martin and J.R.Macdonald, Phys. Rev. A 4, 1974 (1971)

58. R.F.Mathis and W.R.Snow, J. Chem. Phys. 61, 4274 (1974)

59. M.Matic and B.Cobic, J. Phys. B 4, 111 (1971)

60. M.McFarland, D.L.Albritton, F.C.Fehsenfeld, E.E. Ferguson and A.L.Schmeltekopf, J. Chem. Phys. 59, 6620 (1973)

61. M.McFarland, D.L.Albritton, F.C. Fehsenfeld, A.L. Schmeltekopf and E.E.Ferguson, J. Geophys. Res. 79, 2005 (1974)

62. J.W.McGowan and L.Kerwin, Canad. J. Phys. 45, 1451 (1967)

63. E.Murad, J. Chem. Phys. 58, 4374 (1973)

64. M.M.Nakshbandi and J.B.Hasted, Planet. Space Sci. 15, 1781 (1967)

65. V.S.Nikolaev, L.N.Fateeva, I.S.Dmitriev and Ya.A. Teplova, Sov. Phys. JETP 13, 695 (1961)

66. J.O.Olsen and P.Hvelplund, Proc. 8th ICPEAC, Beograd, (1973) p.797

67. J.H.Ormrod and W.L.Michel, Canad. J. Phys. 49, 606 (1971)

68. J.Ostgraard, J.O.Olsen and P.Hvelplund, J. Phys. B 7, 1331 (1974)

69. D.V.Pilipenko and Ya.M.Fogel, Sov. Phys. JETP 17, 1222 (1963)

70. R.F.Potter, J. Chem. Phys. 22, 974 (1954)

71. R. Ranjan and C.C.Goodyear, J. Phys. B 6, 1070 (1973)

72. A.E.Roche and C.C.Goodyear, J. Phys. B 2, 191 (1969)

73. A.E.Roche and C.C.Goodyear, J. Phys. D 4, 1513 (1971)

74. J.A.Rutherford and B.R.Turner, J. Geophys. Res. 72, 3795 (1967)

75. J.A.Rutherford and D.A.Vroom, J. Chem. Phys. 55, 5622 (1971)

76. J.A.Rutherford, R.F.Mathis, B.R.Turner and D.A.Vroom, J. Chem. Phys. 56, 4654 (1972)

77. J.A.Rutherford and D.A.Vroom, J. Chem. Phys. 57, 3087 (1972)

78. J.A.Rutherford and D.A.Vroom, J. Chem. Phys. 57, 309 (1972)

79. J.A.Rutherford and D.A.Vroom, Proc. 8th ICPEAC, Beograd, (1973) p.807

80. N.R.Snow, R.D.Rundel and R.Geballe, Phys. Rev. 178, 228 (1969)

81. E.S.Solov'ev, R.N.Il'in, V.A.Oparin and I.T.Serenkov, Sov. Phys. JETP Lett. 10, 190 (1969)

82. R.F.Stebbings, W.L.Fite and D.G.Hummer, J. Chem. Phys. 33, 1226 (1960)

83. R.F.Stebbings, A.C.H.Smith and H.B.Gilbody, J. Chem. Phys. 38, 2280 (1963)

84. R.F.Stebbings, A.C.H.Smith and H. Ehrhardt, "Atomic Collision Processes" (ed. M.R.C.McDowell) (1964) p.814

85. R.F.Stebbings, B.R.Turner and J.A.Rutherford, J. Geophys. Res. 71, 771 (1966)

86. J.A.Stockdale, R.N.Compton and P.W.Reinhardt, Phys. Rev. 184, 81 (1969)

87. N.Stolterfoht and D.Schneider, Phys. Rev. Lett. 33, 59 (1974)

88. B.R.Turner, J.A.Rutherford and D.M.Compton, J. Chem. Phys. 48, 1602 (1968)

89. B.R.Turner and J.A.Rutherford, J. Geophys. Res. 73, 6751 (1968)

90. J.Van den Bos, Proc. 7th ICPEAC,Amsterdam, (1971) p.510

91. D.Vogt and K.H.Opiela, Phys. Lett. A 54, 331 (1975)

92. M.Vujovic, M.Matic and B.Cobic, Proc. 6th ICPEAC, Cambridge, (1969) p.1020

93. P.Warneck, Planet. Space Sci. 15, 1349 (1967)

94. M.J.Wynn, J.D.Martin and T.L.Bailey, J. Chem. Phys. 52, 191 (1970)

II. Tables of Experimental Data

A) Electron Capture Cross Sections of Oxygen Atom and Positive Ions, O^0, O^+, O^{2+}, O^{3+}, O^{4+}, O^{5+}, O^{6+}, O^{7+}, O^{8+}.

authors	year	energy(eV)	target	reference
(σ_{01})				
Fogel' et al.	1959	10,000-65,000	H_2,He,N_2, O_2,Ne,Ar, Kr,Xe	36
Jorgensen,Kuyatt	1965	50,000-400,000	H_2,He,O_2	49
Dmitriev et al.	1966	560,000	He,N_2,Ar	19
Olsen,Hvelplund	1974	100,000-500,000	H_2	66
(σ_{10})				
Hasted	1951	25-900	He,N_2,Ar	42
Potter	1954	10-250	N_2,O_2	70
Stebbings et al.	1960	300-800	H	82
Jorgensen,Kuyatt	1965	50,000-400,000	H_2,He,O_2	49
Copsey et al.	1966	300°K	O_2	11
Goldan et al.	1966	300°K	NO	40
Stebbings et al.	1966	20-100	N_2,O_2	85
Warneck	1967	700°-1,100°K	O_2	93
Bohme et al.	1967	0.043-1.9	O_2	5
Nakshbandi,Hasted	1967	77-375°K	O_2	64
Turner,Rutherford	1968	2-500	H_2O	89
Turner et al.	1968	100	NO	88
Dunkin et al.	1968	300°-600°K	N_2,O_2,CO_2	22
Lo et al.	1969	30,000-2,000,000	O	55

Johnsen et al.	1970	0.04-12.8	CO_2	48
Ormrod,Michel	1971	20,000-90,000	N_2,Ar	67
Lo et al.	1971	30,000-2,000,000	O	54
Rutherford,Vroom	1971	0.5-500	N_2	75
Rutherford et al.	1972	3-500	Ca	76
Rutherford et al.	1972	5-500	Fe	78
Murad	1973	6.3-97	CO	63
McFarland et al.	1974	0.35-46	NO	61
Kaneko,Kobayashi	1974	0.68-4.4	N_2	50
Olsen,Hvelplund	1974	100,000-500,000	H_2	68
Kosmider,Hasted	1975	0.043-5.00	O_2,CO,NO	52
($\sigma_{1\bar{1}}$)				
Fogel',Krupnik	1956	15,000-41,400	H_2,N_2,O_2	32
Fogel' et al.	1957	10,000-55,000	H_2,He,N_2, O_2,Ne,Ar, Kr,Xe	33
Il'in,Solov'ev	1961	30,000-187,000	Ar	47
Jorgensen,Kuyatt	1965	50,000-400,000	H_2,He,O_2	49
Dmitriev et al.	1966	560,000	He,N_2,Ar	19
Vujovic,Cobic	1969	5,000-27,000	Kr	92
Cobic et al.	1970	5,000-27,000	Kr	10
(σ_{21})				
Nikolaev et al.	1961	5,300,000	He,N_2	65
Jorgensen,Kuyatt	1965	50,000-400,000	H_2,He,O_2	49
Ormrod,Michel	1971	30,000-90,000	N_2,Ar	67
Olsen,Hvelplund	1974	100,000-500,000	H_2	68

(σ_{20})				
Jorgensen,Kuyatt	1965	50,000-400,000	H_2,He,O_2	19
(σ_{32})				
Nikolaev et al.	1961	5,300,000	He,N_2	65
Macdonald,Martin	1969	7,000,000-16,000,000	N_2	55
Martin,Macdonald	1971	7,000,000-16,000,000	He,N_2	57
Crandall et al.	1977	10,000-80,000	H_2	13
(σ_{43})				
Nikolaev et al.	1961	5,300,000	He,N_2	65
Macdonald,Martin	1969	7,000,000-38,000,000	N_2	55
Martin,Macdonald	1971	7,000,000-38,000,000	He,N_2,Ar	56, 57
Crandall et al.	1977	22,000-105,000	H_2	13
(σ_{42})				
Martin,Macdonald	1971	7,000,000-9,000,000	N_2	56, 57
(σ_{54})				
Nikolaev et al.	1961	5,300,000	He,N_2	65
Macdonald,Martin	1969	7,000,000-38,000,000	N_2	55
Martin,Macdonald	1971	7,000,000-40,000,000	He,N_2,Ar	56, 57
Crandall et al.	1977	30,000-105,000	H_2	13

(σ_{53})

Macdonald,Martin	1969	7,000,000-20,000,000	N_2	55
Martin,Macdonald	1971	7,000,000-20,000,000	He,N_2,Ar	56, 57

(σ_{65})

Nikolaev et al.	1961	5,300,000	He,N_2	65
Macdonald,Martin	1969	7,000,000-40,000,000	N_2	55
Martin,Macdonald	1971	7,000,000-40,000,000	He,N_2,Ar	56, 57
Crandall et al.	1977	35,000-70,000	H_2	13
Crandall et al.	1977	35,000-70,000	He	14

(σ_{64})

Macdonald,Martin	1969	7,000,000-38,000,000	N_2	55
Martin,Macdonald	1971	7,000,000-38,000,000	He,N_2,Ar	56, 57
Crandall	1977	35,000-70,000	He	14

(σ_{63})

Macdonald,Martin	1969	7,000,000-10,000,000	N_2	55
Martin,Macdonald	1971	7,000,000-10,000,000	N_2,Ar	56, 57

(σ_{76})

Macdonald,Martin	1969	7,000,000-40,000,000	N_2	55

Martin,Macdonald	1971	7,000,000-40,000,000	He,N_2,Ar	56, 57
(σ_{75})				
Macdonald,Martin	1969	7,000,000-40,000,000	N_2	55
Martin,Macdonald	1971	7,000,000-40,000,000	He,N_2,Ar	56, 57
(σ_{74})				
Macdonald,Martin	1969	7,000,000-20,000,000	N_2	55
Martin,Macdonald	1971	7,000,000-25,000,000	He,N_2,Ar	56, 57
(σ_{73})				
Martin,Macdonald	1971	7,000,000	Ar	56, 57
(σ_{87})				
Macdonald,Martin	1969	7,000,000-40,000,000	N_2	55
Martin,Macdonald	1971	7,000,000-40,000,000	He,N_2,Ar	56, 57
(σ_{86})				
Macdonald,Martin	1969	7,000,000-40,000,000	N_2	55
Martin,Macdonald	1971	7,000,000-40,000,000	He,N_2,Ar	56, 57
(σ_{85})				
Macdonald,Martin	1969	7,000,000-30,000,000	N_2	55

Martin,Macdonald	1971	7,000,000-35,000,000	N_2,Ar	56, 57

(σ_{84})

Martin,Macdonald	1971	7,000,000-20,000,000	N_2,Ar	56, 57

B) Electron Loss Cross Sections of Oxygen Negative Ion, Atom and Positive Ions; O^-, $O°$, O^+, O^{2+}, O^{3+}, O^{4+}, O^{5+}, O^{6+}, O^{7+}.

($\sigma_{\bar{I}0}$)

Hasted	1952	150-4,000	He,Ar	41
Hasted,Smith	1956	10-2,500	N_2,O_2	43
Jorgensen,Kuyatt	1965	50,000-4,000,000	H_2,He,O_2	49
Dmitriev et al.	1966	560,000	He,N_2,Ar	19
Rutherford,Turner	1967	2-400	O_2	74
Stockdale et al.	1969	0.25-1.5	NO_2	86
Roche,Goodyear	1969	3-100	O_2	73
Snow et al.	1969	500-4,000	O_2	80
Wynn et al.	1970	4-400	He,Ar	94
Bailey,Mahadevan	1970	4-350	O_2	1
Ormrod,Michel	1971	20,000-65,000	N_2,Ar	67
Matić,Ćobić	1971	5,000-30,000	N_2,O_2,Ne, Ar,Kr,Xe	59
Roche,Goodyear	1971	4-100	O_2	73
Dimov,Roslyakov	1972	300-600	O_2	16
Ranjan,Goodyear	1973	20-100	N_2,O_2	71
Mathis,Snow	1974	10-10,000	O_2	58

Olsen,Hvelplund	1974	100,000-500,000	H_2	66
Vogt,Opiela	1975	20-5,000	O_2,NO_2,SO_2	91
Bennett et al.	1975	800-4,000	He,N_2,O_2,Ar	2
($\sigma_{\bar{I}1}$)				
Jorgensen,Kuyatt	1965	50,000-400,000	H_2,He,O_2	49
Dmitriev et al.	1966	560,000	He,N_2,Ar	19
Matic,Cobic	1971	5,000-30,000	N_2,O_2,Ne, Ar,Kr,Xe	59
Olsen,Hvelplund	1974	100,000-500,000	H_2	66
($\sigma_{\bar{I}2}$)				
Dmitriev et al.	1966	560,000	He,N_2,Ar	19
Matic,Cobic	1971	10,000-30,000	N_2,O_2,Ne, Ar,Kr,Xe	59
Olsen,Hvelplund	1974	100,000-500,000	H_2	66
(σ_{01})				
Fogel' et al.	1959	10,000-65,000	H_2,He,N_2, O_2,Ne,Ar, Kr,Xe	36
Jorgensen,Kuyatt	1965	50,000-400,000	H_2,He,O_2	49
Ormrod,Michel	1971	20,000-90,000	N_2,Ar	67
Olsen,Hvelplund	1974	100,000-500,000	H_2	68
(σ_{02})				
Jorgensen,Kuyatt	1965	50,000-400,000	H_2,He,O_2	49
Olsen,Hvelplund	1974	100,000-500,000	H_2	68

(σ_{12})				
Fogel',Krupnik	1956	12,500-41,000	H_2,N_2,O_2	32
Jorgensen,Kuyatt	1965	50,000-400,000	H_2,He,O_2	49
Dmitriev et al.	1966	560,000	He,N_2,Ar	19
Lo et al.	1971	30,000-2,000,000	O	54
Olsen,Hvelplund	1974	100,000-500,000	H_2	68
(σ_{13})				
Dmitriev et al.	1963	5,300,000	He	18
Dmitriev et al.	1966	560,000	He,N_2,Ar	19
Lo et al.	1971	200,000-2,000,000	O	54
(σ_{14})				
Dmitriev et al.	1966	560,000	N_2,Ar	19
Lo et al.	1971	250,000-2,000,000	O	54
(σ_{15})				
Lo et al.	1971	1,100,000-1,750,000	O	54
(σ_{23})				
Dmitriev et al.	1962	5,300,000	He,N_2	17
Jorgensen,Kuyatt	1965	50,000-400,000	H_2,He,O_2	49
Macdonald,Martin	1969	7,000,000-15,000,000	N_2	55
Olsen,Hvelplund	1974	300,000-500,000	H_2	68

(σ_{24})

Dmitriev et al.	1963	5,300,000	N_2	18
Macdonald,Martin	1969	8,000,000-12,000,000	N_2	55
Martin,Macdonald	1971	7,000,000-15,000,000	N_2	57

(σ_{25})

Dmitriev et al.	1963	5,300,000	N_2	18
Macdonald,Martin	1969	12,000,000	N_2	55
Martin,Macdonald	1971	7,000,000-15,000,000	N_2	56, 57

(σ_{34})

Dmitriev et al.	1962	5,300,000	He,N_2	17
Macdonald,Martin	1969	7,000,000-20,000,000	N_2	55
Martin,Macdonald	1971	7,000,000-20,000,000	He,N_2,Ar	56, 57

(σ_{35})

Dmitriev et al.	1963	5,300,000	He,N_2	18
Macdonald,Martin	1969	7,000,000-20,000,000	N_2	55
Martin,Macdonald	1971	7,000,000-20,000,000	He,N_2,Ar	56, 57

(σ_{36})

Macdonald,Martin	1969	7,000,000-20,000,000	N_2	55

Martin,Macdonald	1971	7,000,000-20,000,000	N_2,Ar	56, 57
(σ_{45})				
Dmitriev et al.	1962	5,300,000	He,N_2	17
Macdonald,Martin	1969	7,000,000-40,000,000	N_2	55
Martin,Macdonald	1971	7,000,000-40,000,000	He,N_2,Ar	56, 57
(σ_{46})				
Dmitriev et al.	1963	5,300,000	He,N_2	18
Macdonald,Martin	1969	7,000,000-40,000,000	N_2	55
Martin,Macdonald	1971	7,000,000-40,000,000	He,N_2,Ar	56, 57
(σ_{47})				
Macdonald,Martin	1969	15,000,000-35,000,000	N_2	55
Martin,Macdonald	1971	15,000,000-35,000,000	N_2,Ar	56, 57
(σ_{56})				
Dmitriev et al.	1962	5,300,000	He,N_2	17
Macdonald,Martin	1969	7,000,000-40,000,000	N_2	55
Martin,Macdonald	1971	7,000,000-40,000,000	He,N_2,Ar	56, 57

(σ_{57})

Macdonald,Martin	1969	9,000,000-40,000,000	N_2	55
Martin,Macdonald	1971	9,000,000-40,000,000	He,N_2,Ar	56, 57

(σ_{58})

Macdonald,Martin	1969	20,000,000-25,000,000	N_2	55
Martin,Macdonald	1971	20,000,000-40,000,000	N_2,Ar	56, 57

(σ_{67})

Dmitriev et al.	1962	5,300,000	He,N_2	17
Macdonald,Martin	1969	7,000,000-40,000,000	N_2	55
Martin,Macdonald	1971	7,000,000-40,000,000	He,N_2,Ar	56, 57

(σ_{68})

Macdonald, Martin	1969	12,000,000-40,000,000	N_2	55
Martin,Macdonald	1971	10,000,000-40,000,000	He,N_2,Ar	56, 57

(σ_{78})

Macdonald,Martin	1969	7,000,000-40,000,000	N_2	55
Martin,Macdonald	1971	7,000,000-40,000,000	He,N_2,Ar	56, 57

C) Cross Sections of Ionization, Slow Ion Production and Electron Production by Oxygen Negative and Positive Ions; O^-, O^+.

$(\sigma_{-1}^{i}, \sigma_{-1}^{+})$				
Fogel' et al.	1960	10,000-50,000	H_2,He,O_2 Ne,Ar,Kr, Xe	37
Dimov,Roslyakov	1972	300-600	O_2	16
$(\sigma_{1}^{+}, \sigma_{1}^{-}, \sigma_{1}^{i})$				
Il'in,Solv'ev	1961	30,000-187,000	Ar	47

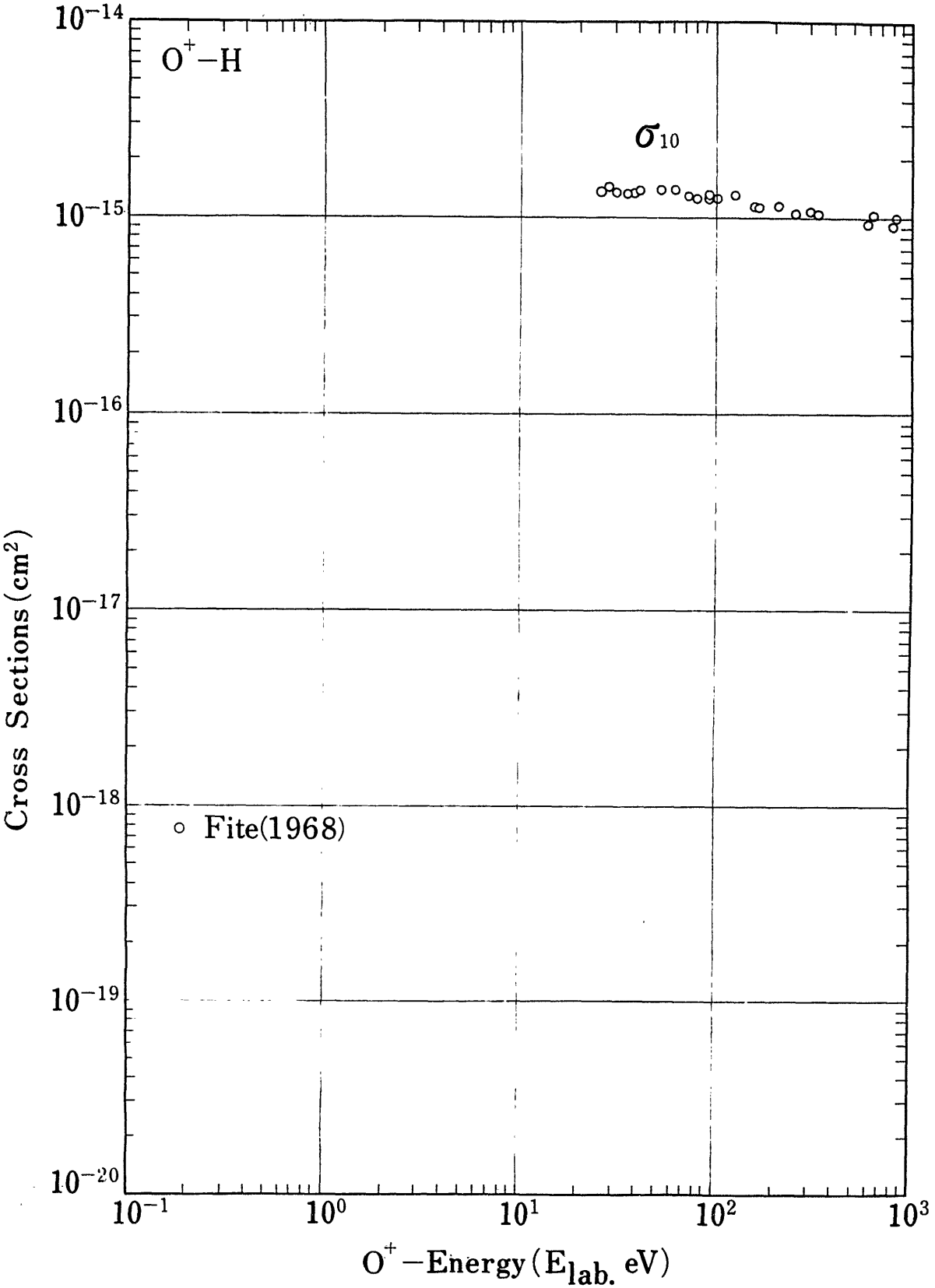


Fig. 1−a Charge Changing Cross Sections of O^+ in H

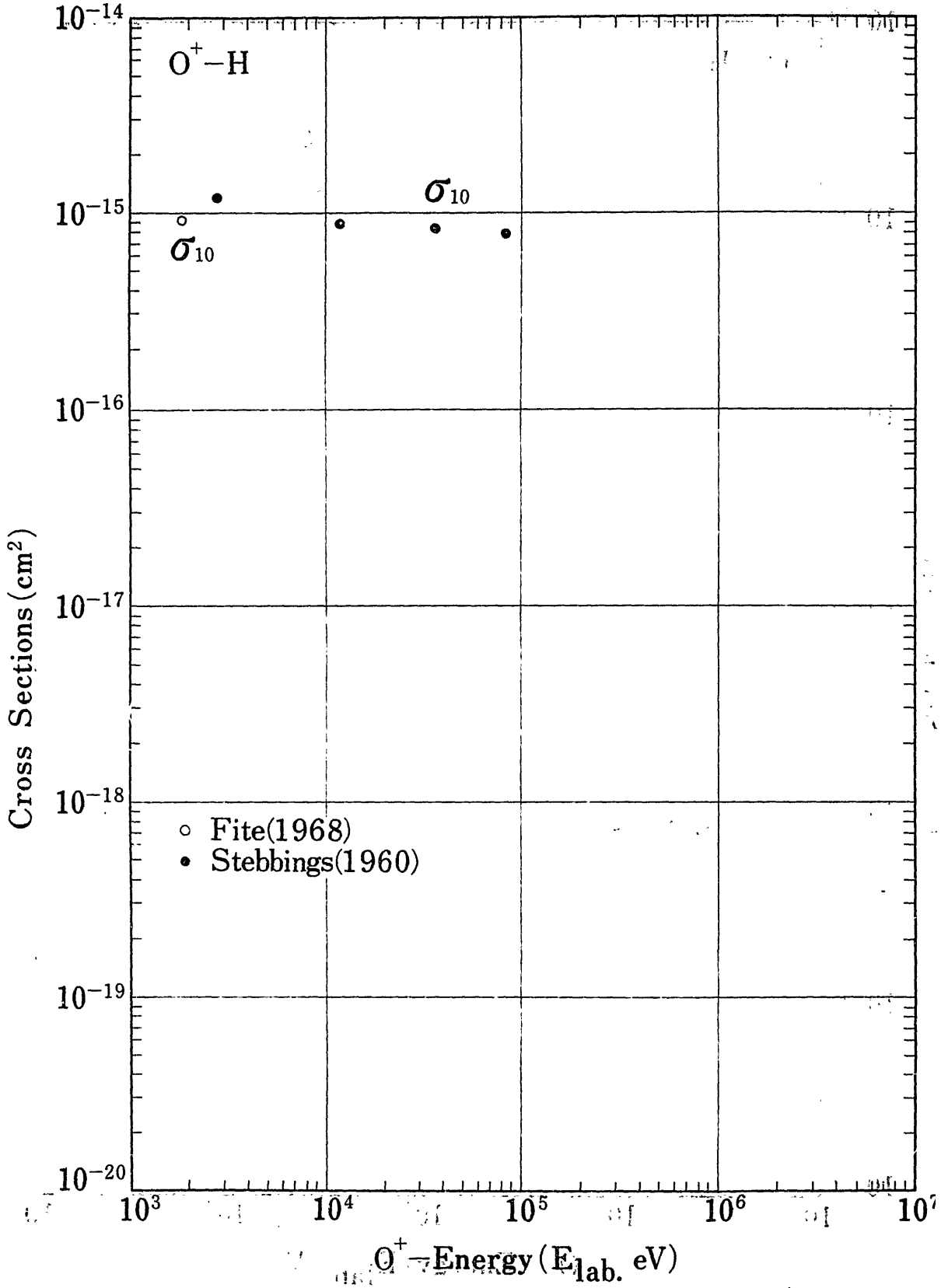


Fig. 1-b Charge Changing Cross Sections of O^+ in H

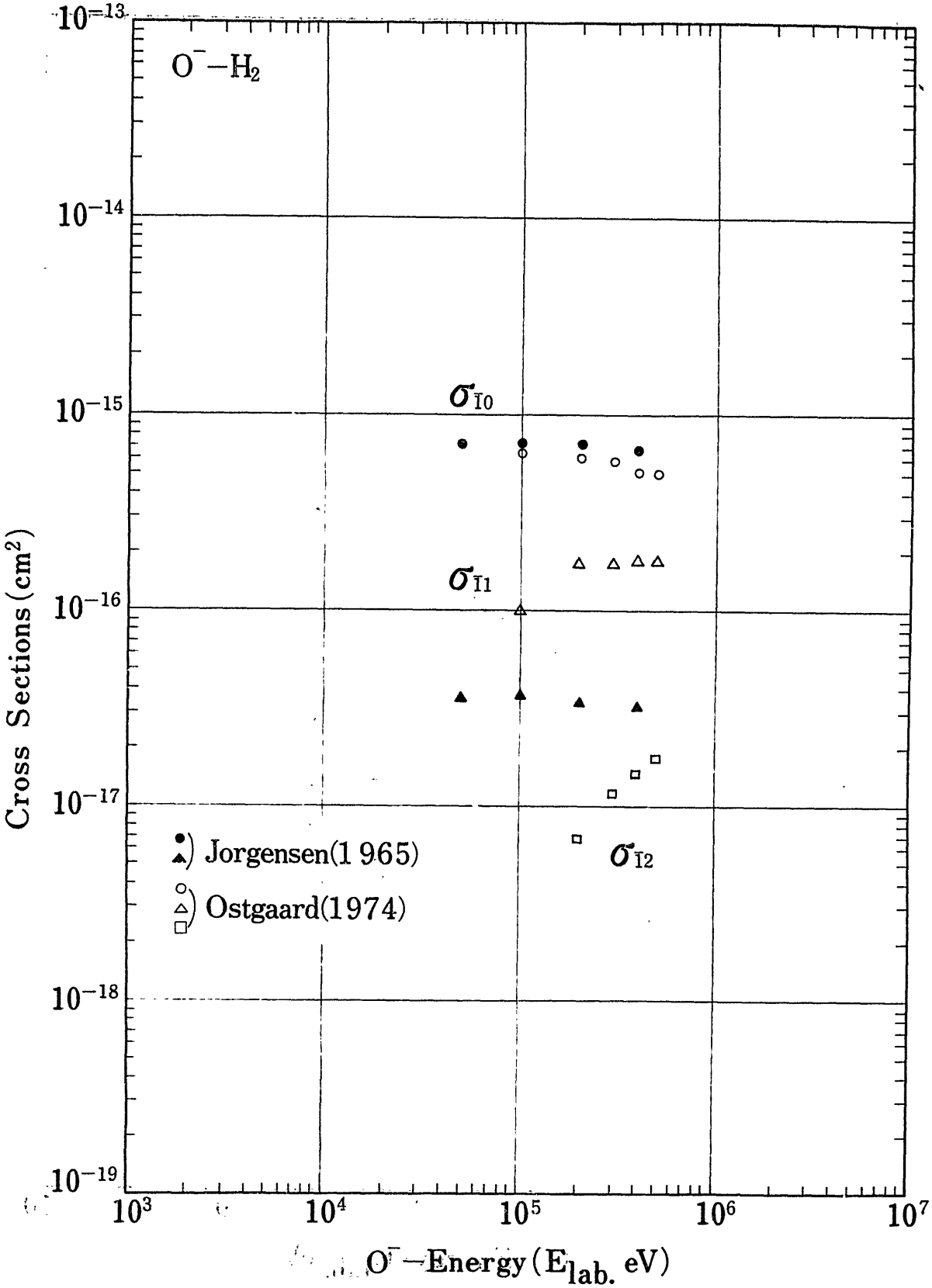


Fig. 2 Charge Changing Cross Sections of O^- in H_2

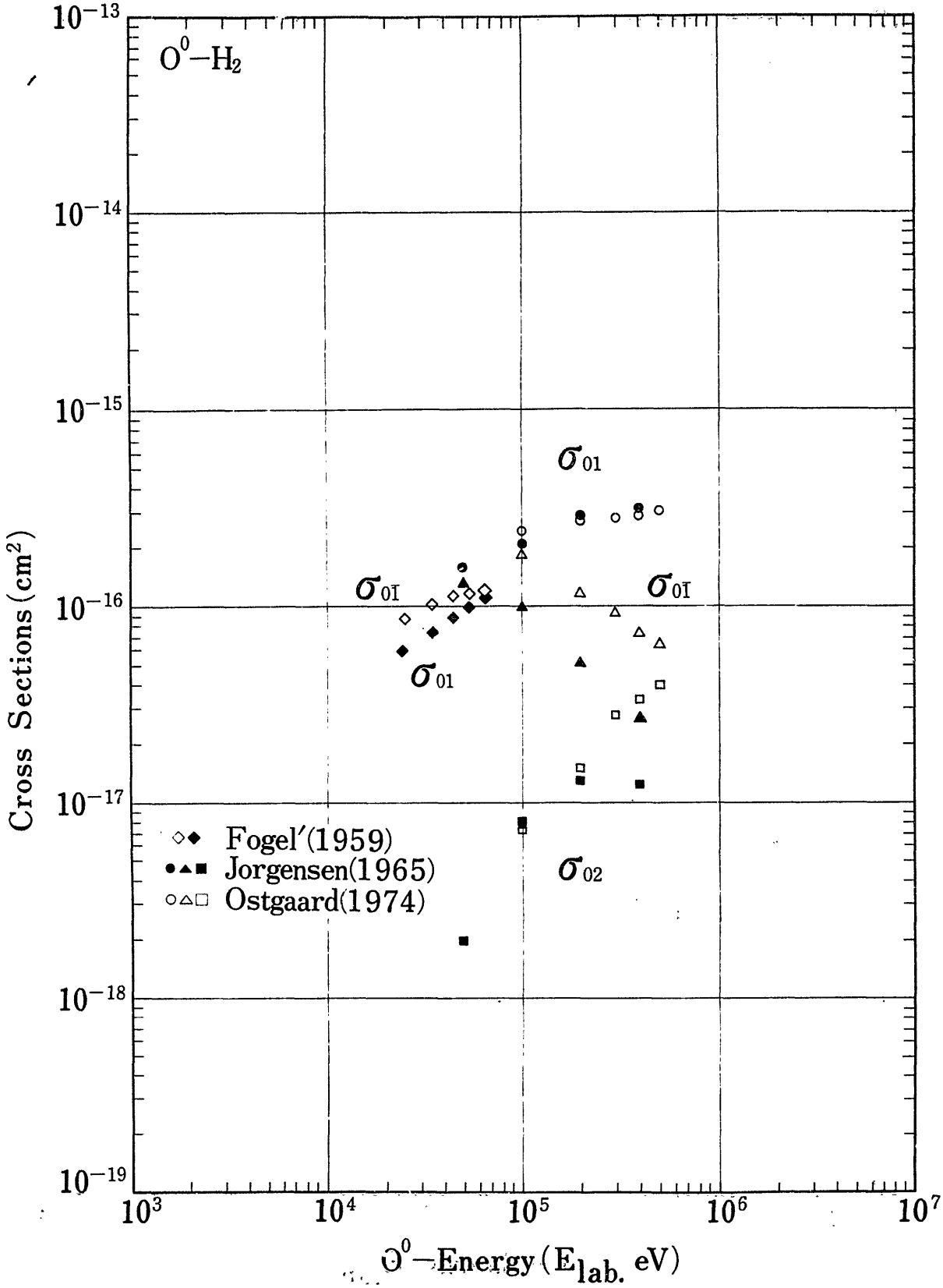


Fig.3 Charge Changing Cross Sections of O^0 in H_2

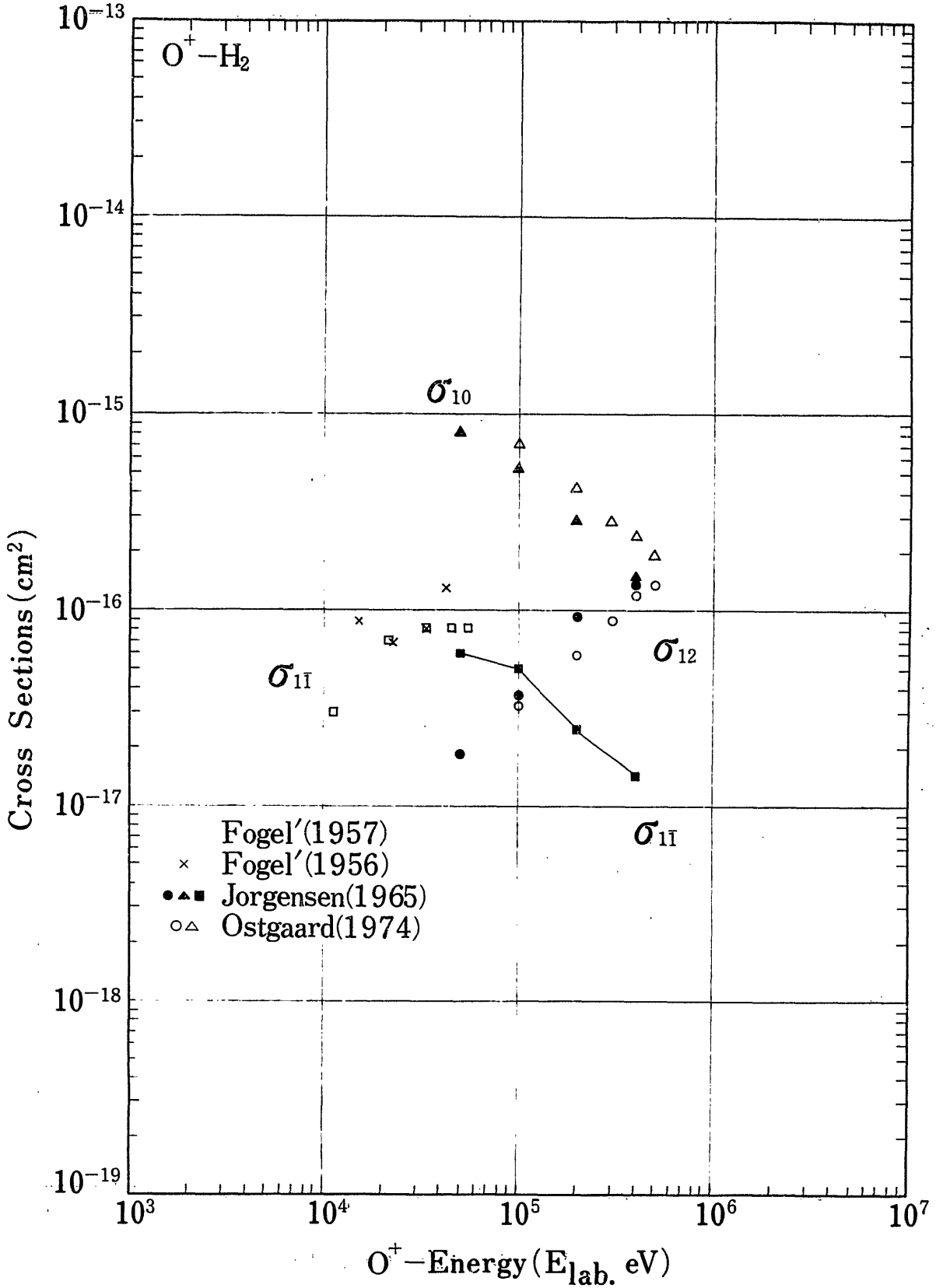


Fig.4 Charge Changing Cross Sections of O^+ in H_2

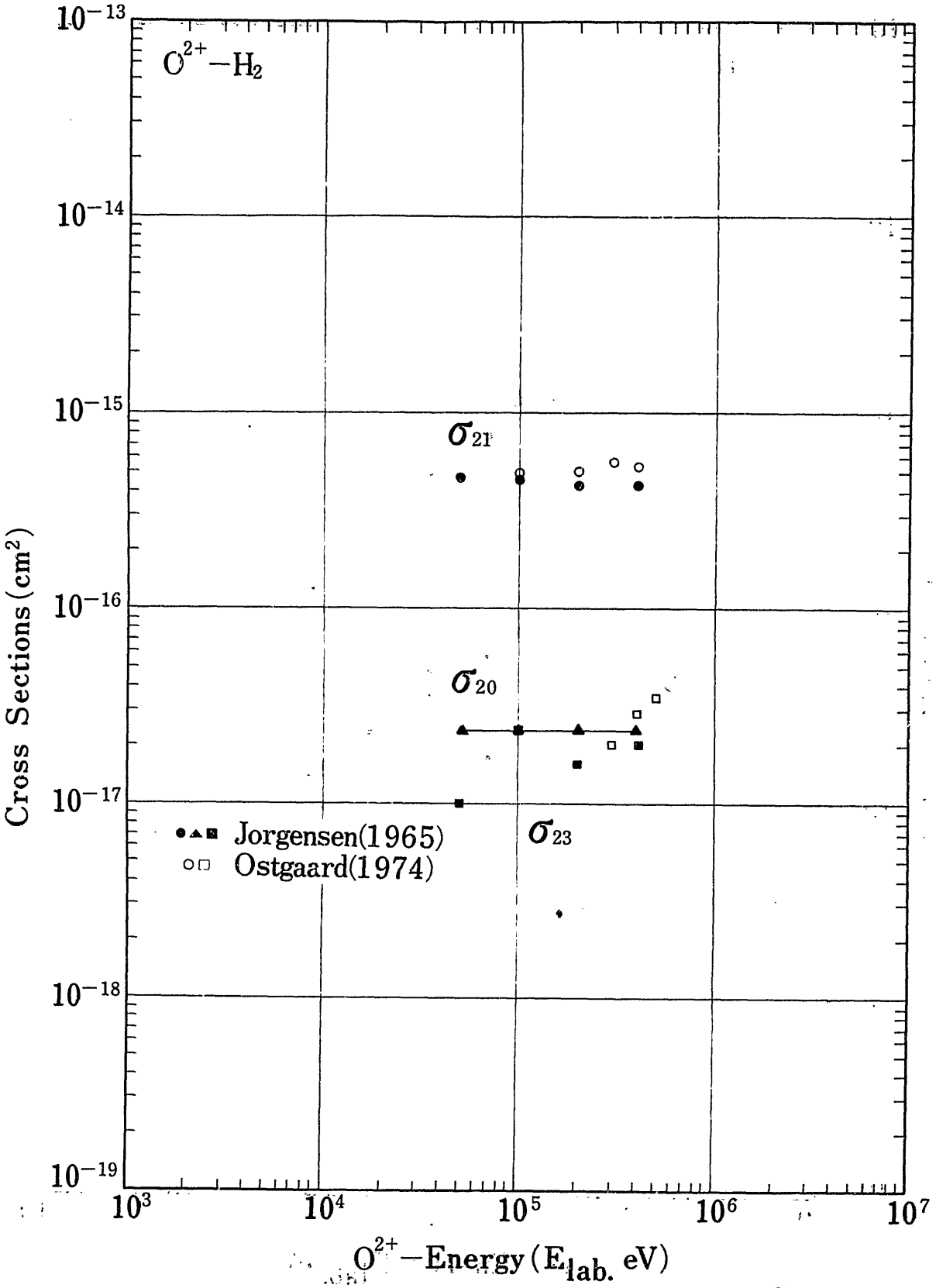


Fig.5 Charge Changing Cross Sections of O^{2+} in H_2

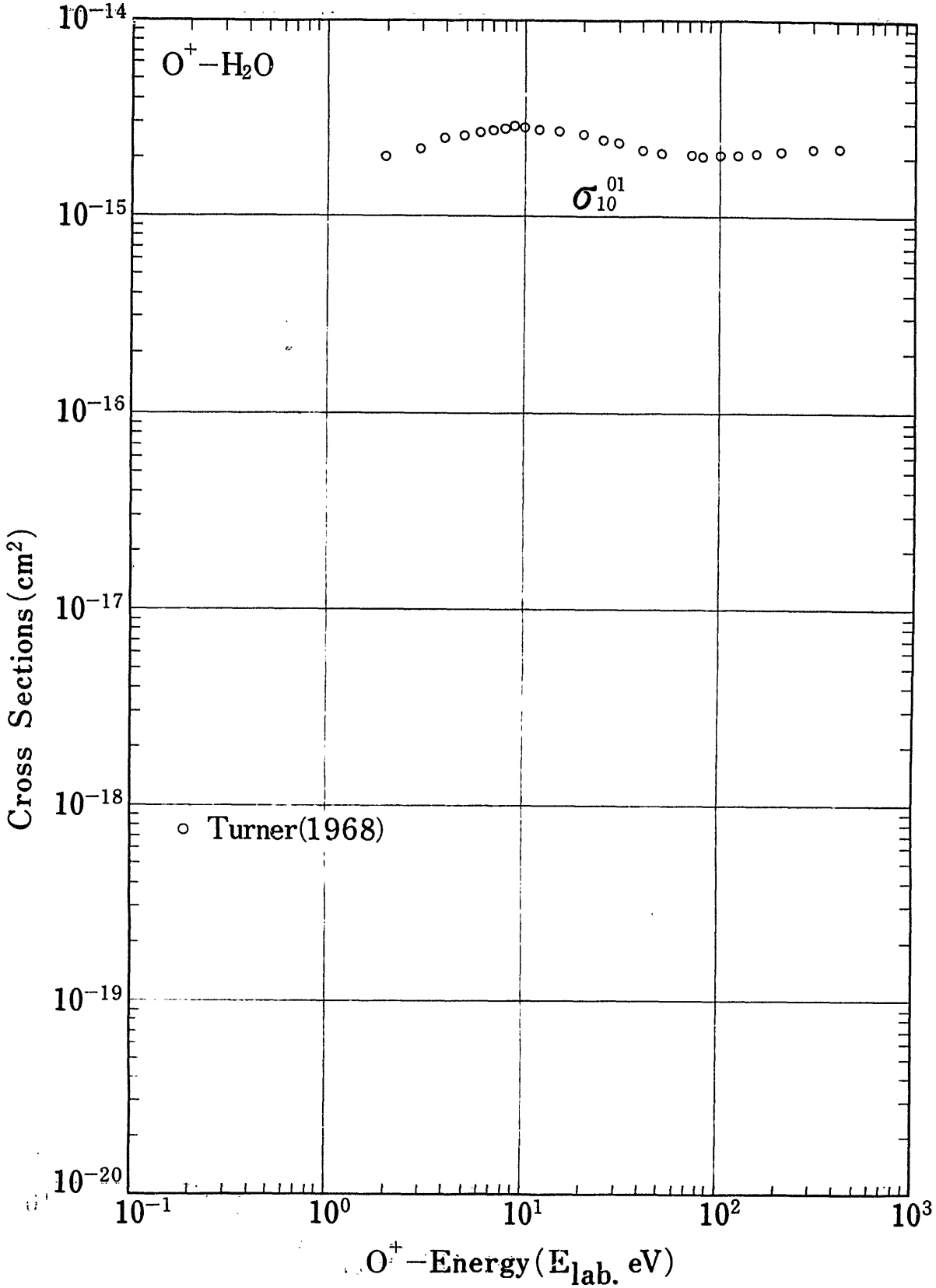


Fig.6 Charge Changing Cross Sections of O^+ in H_2O

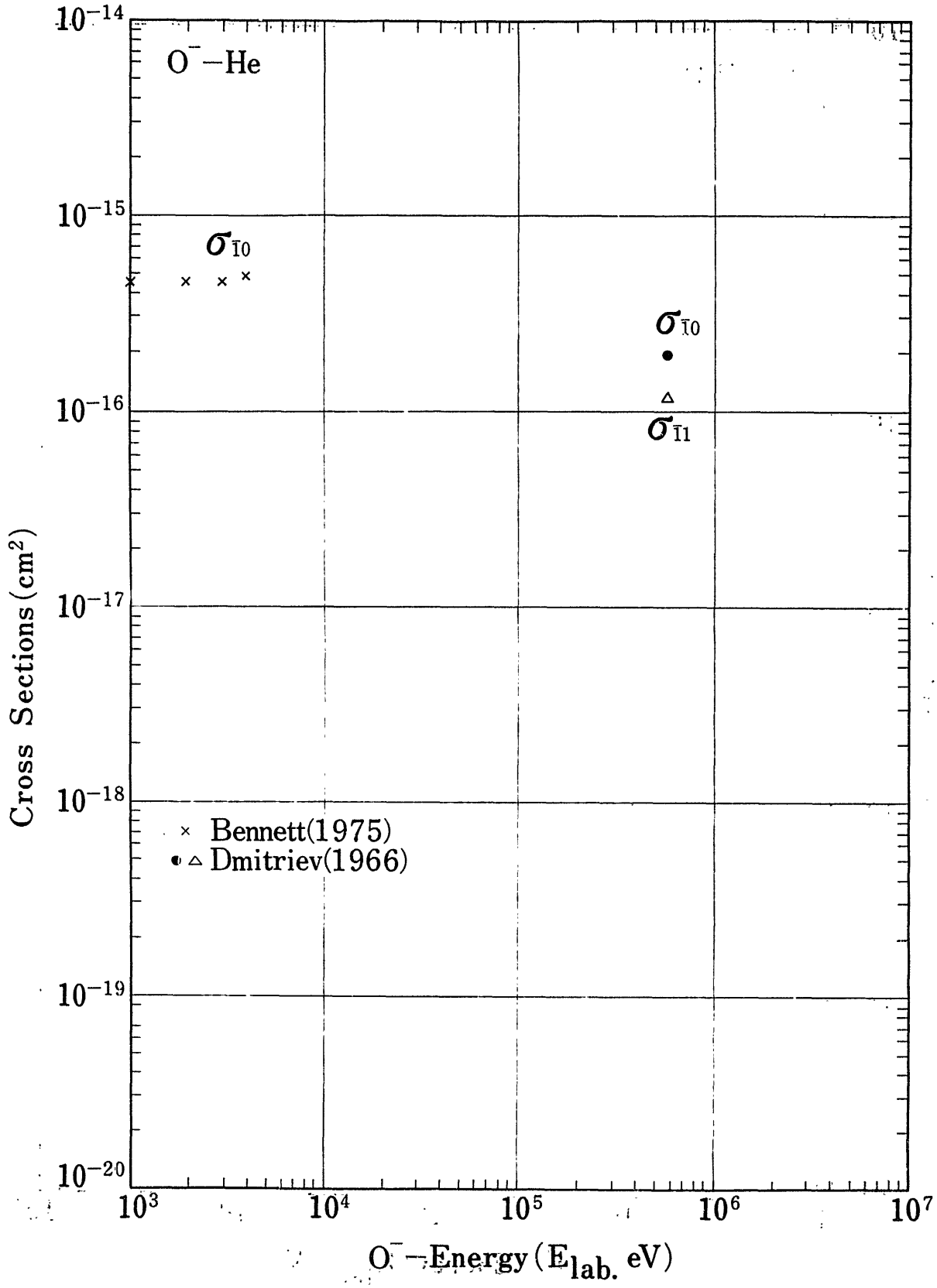


Fig. 7 Charge Changing Cross Sections of O^- in He

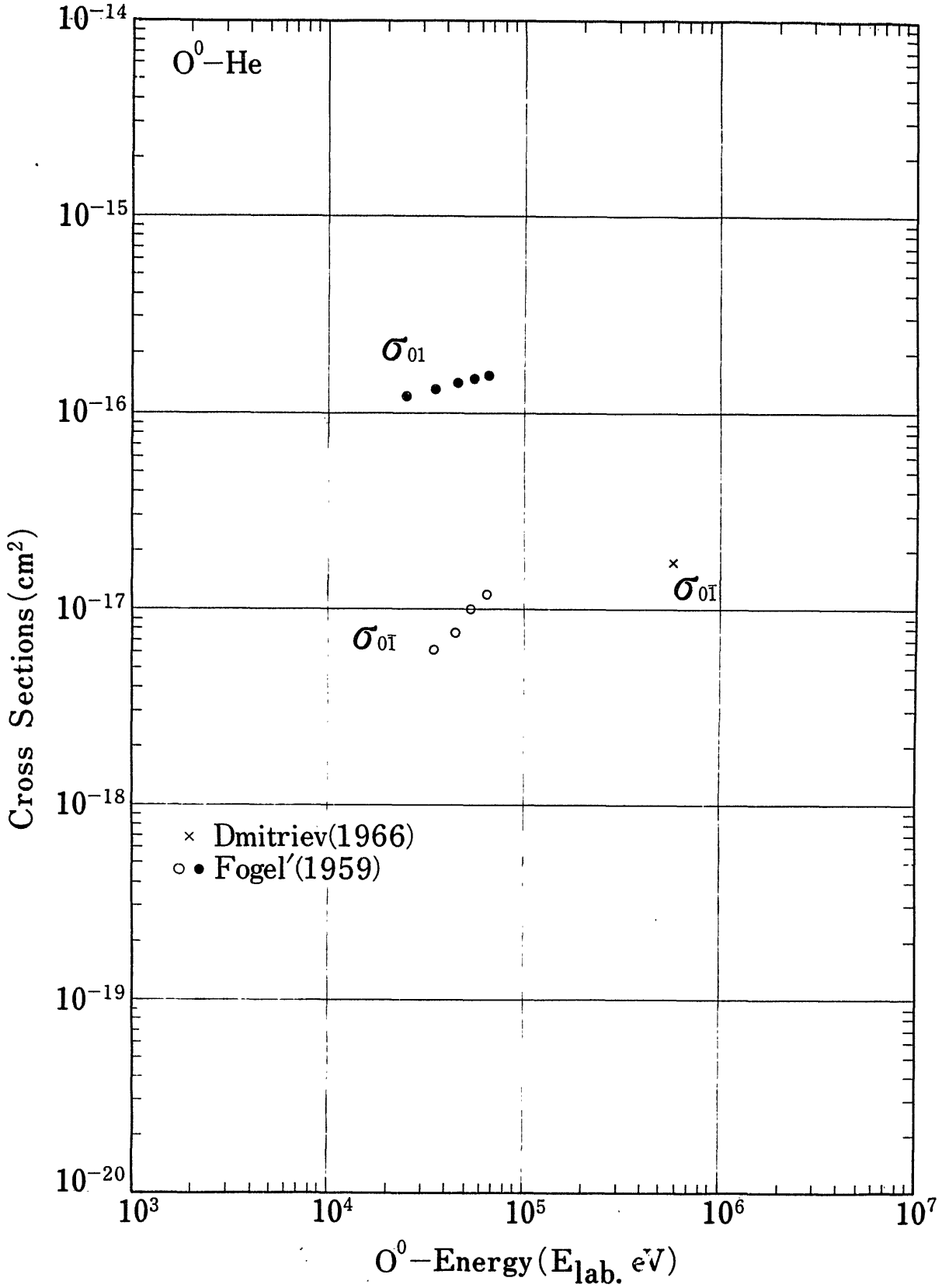


Fig.8 Charge Changing Cross Sections of O^0 in He

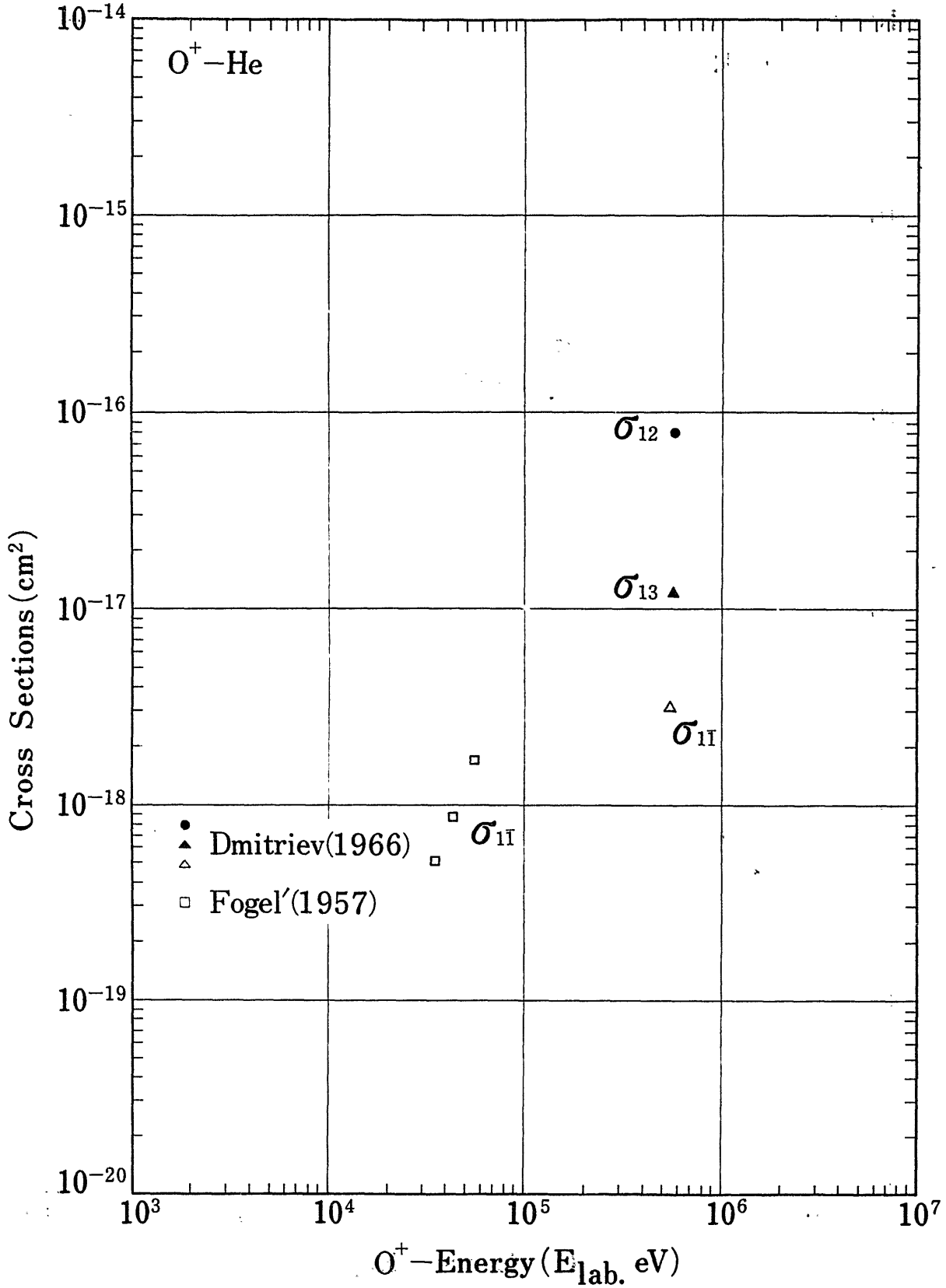


Fig. 9 Charge Changing Cross Sections of O^+ in He

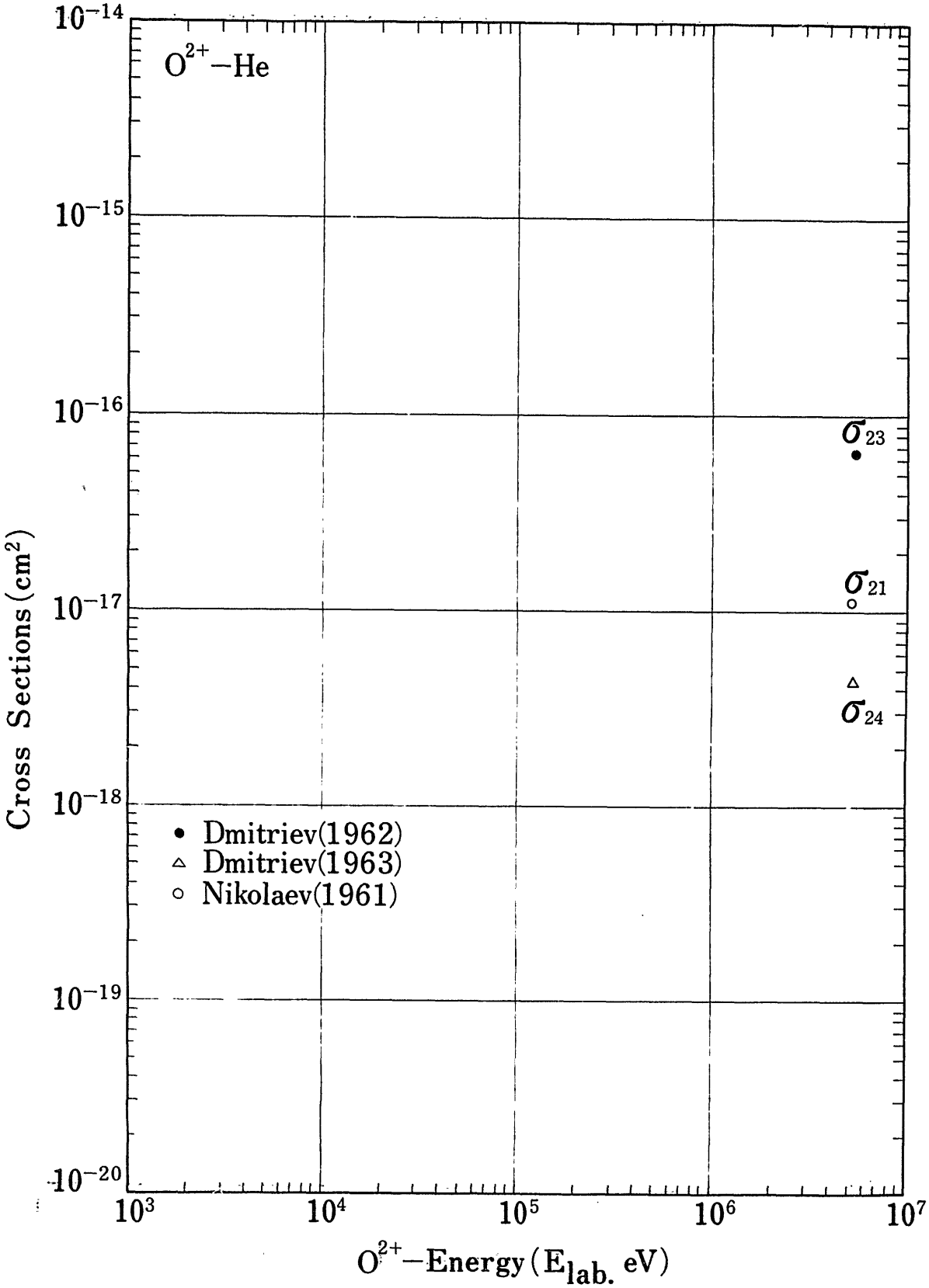


Fig.10 Charge Changing Cross Sections of O^{2+} in He

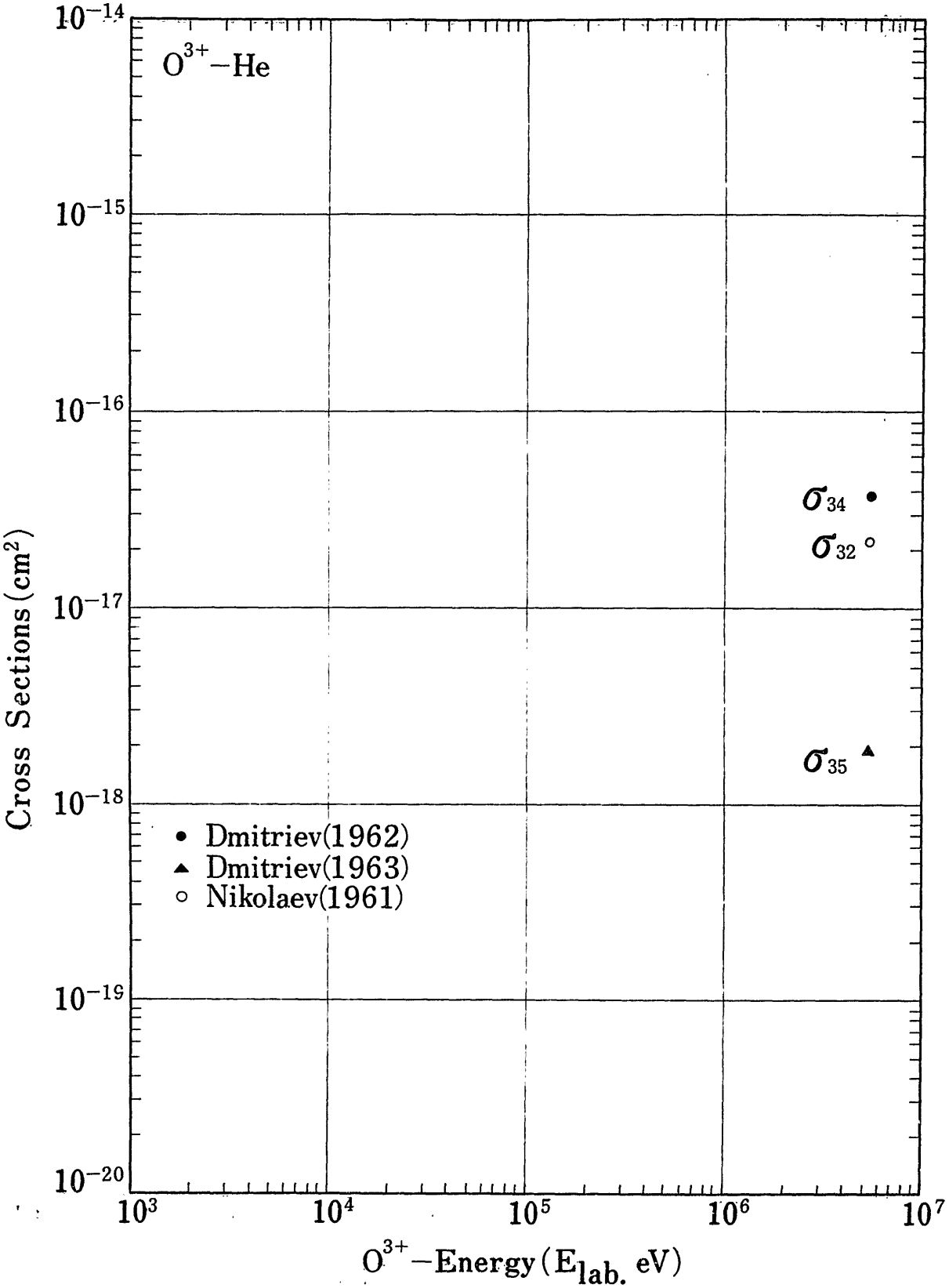


Fig.11 Charge Changing Cross Sections of O^{3+} in He

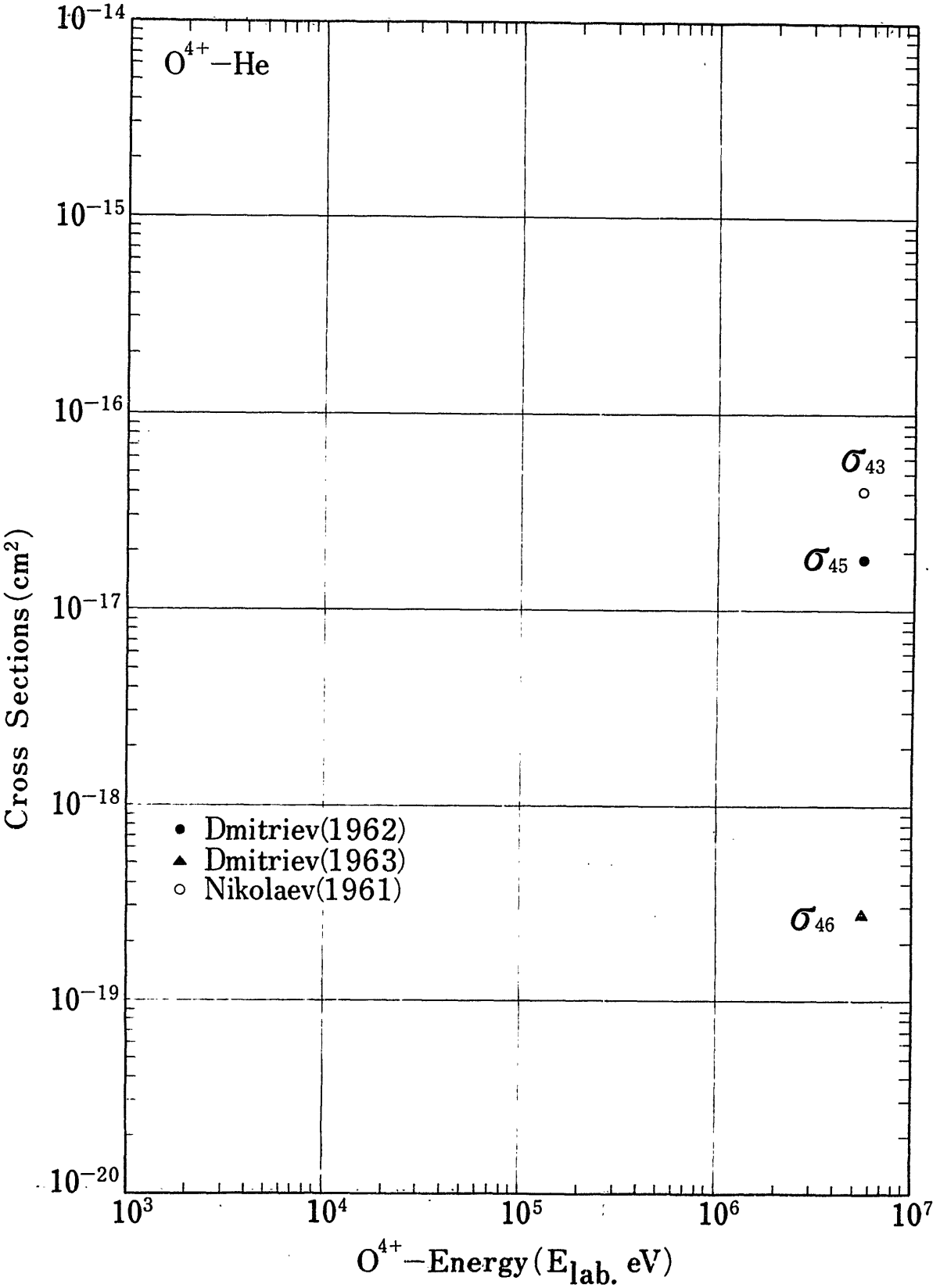


Fig.12 Charge Changing Cross Sections of O^{4+} in He

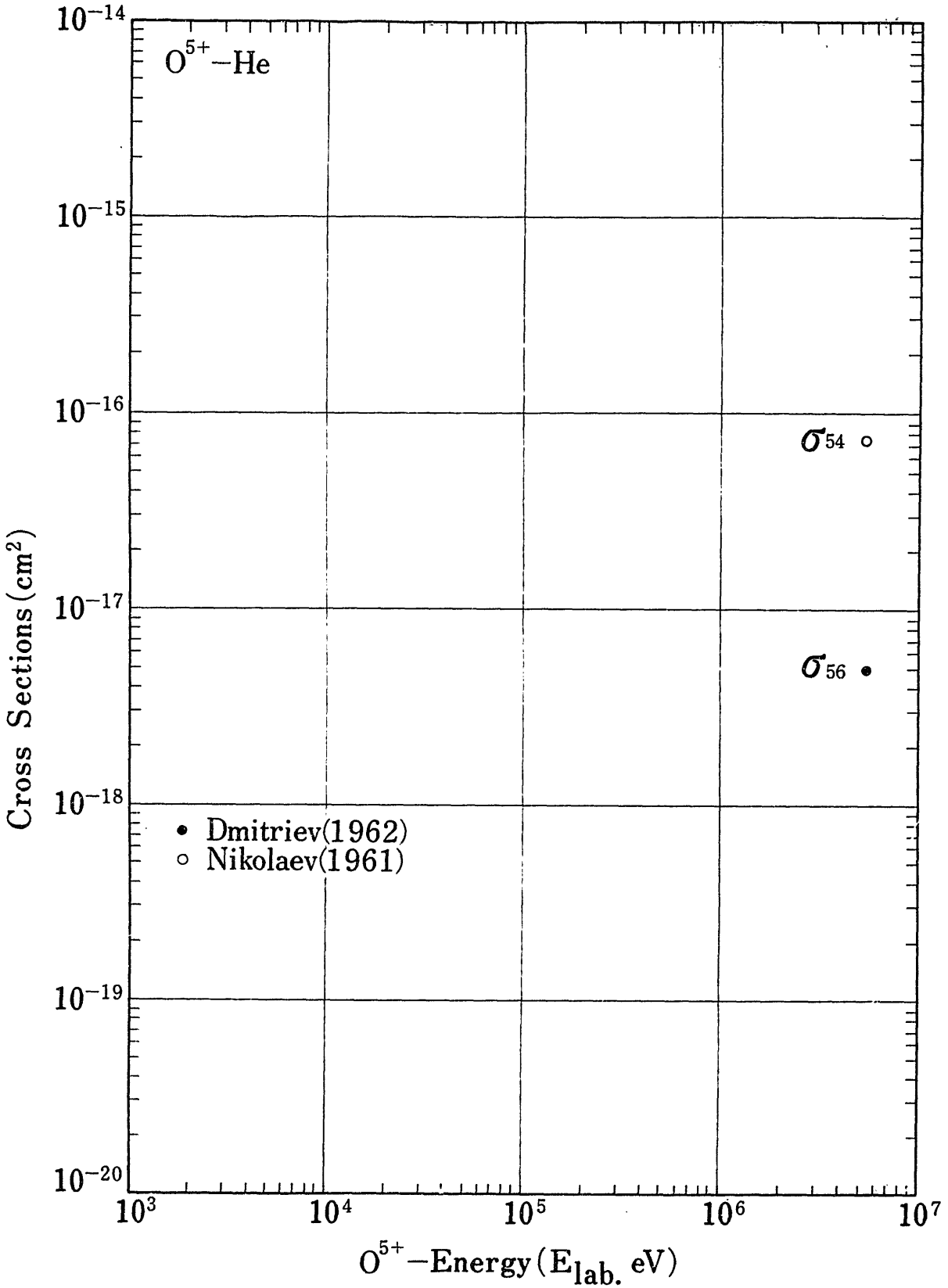


Fig.13 Charge Changing Cross Sections of O^{5+} in He

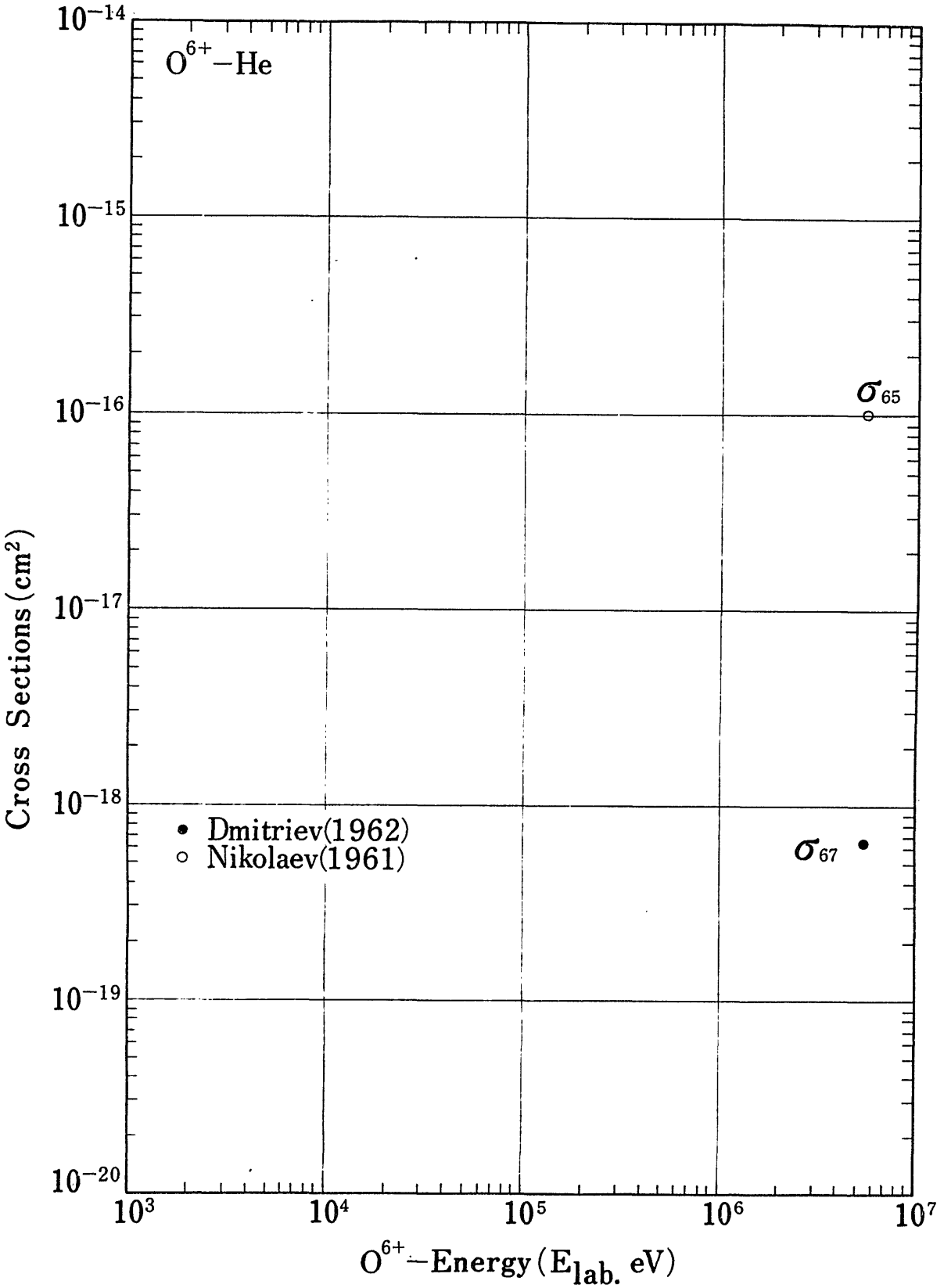


Fig.14 Charge Changing Cross Sections of O^{6+} in He

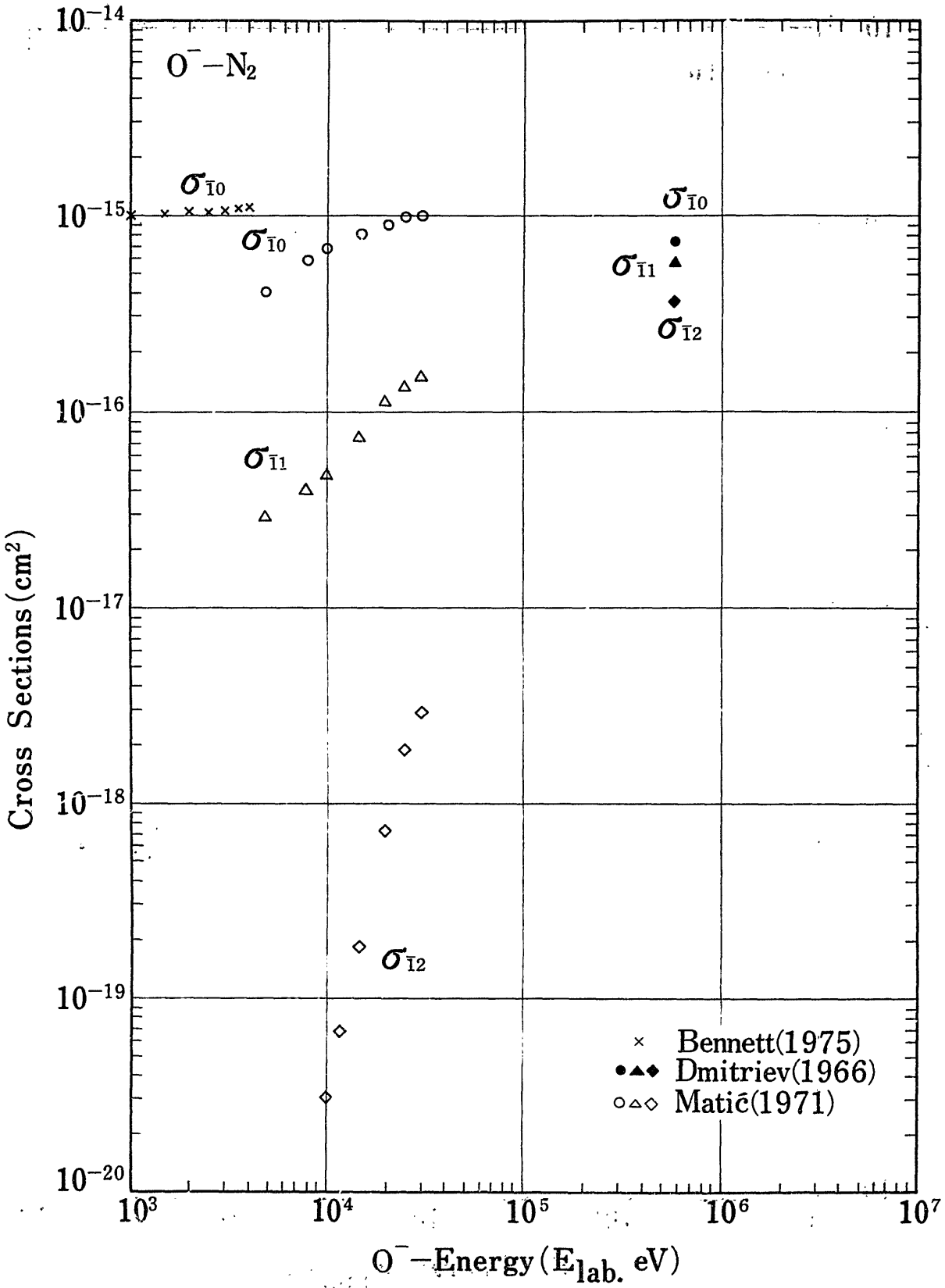


Fig.15 Charge Changing Cross Sections of O^- in N_2

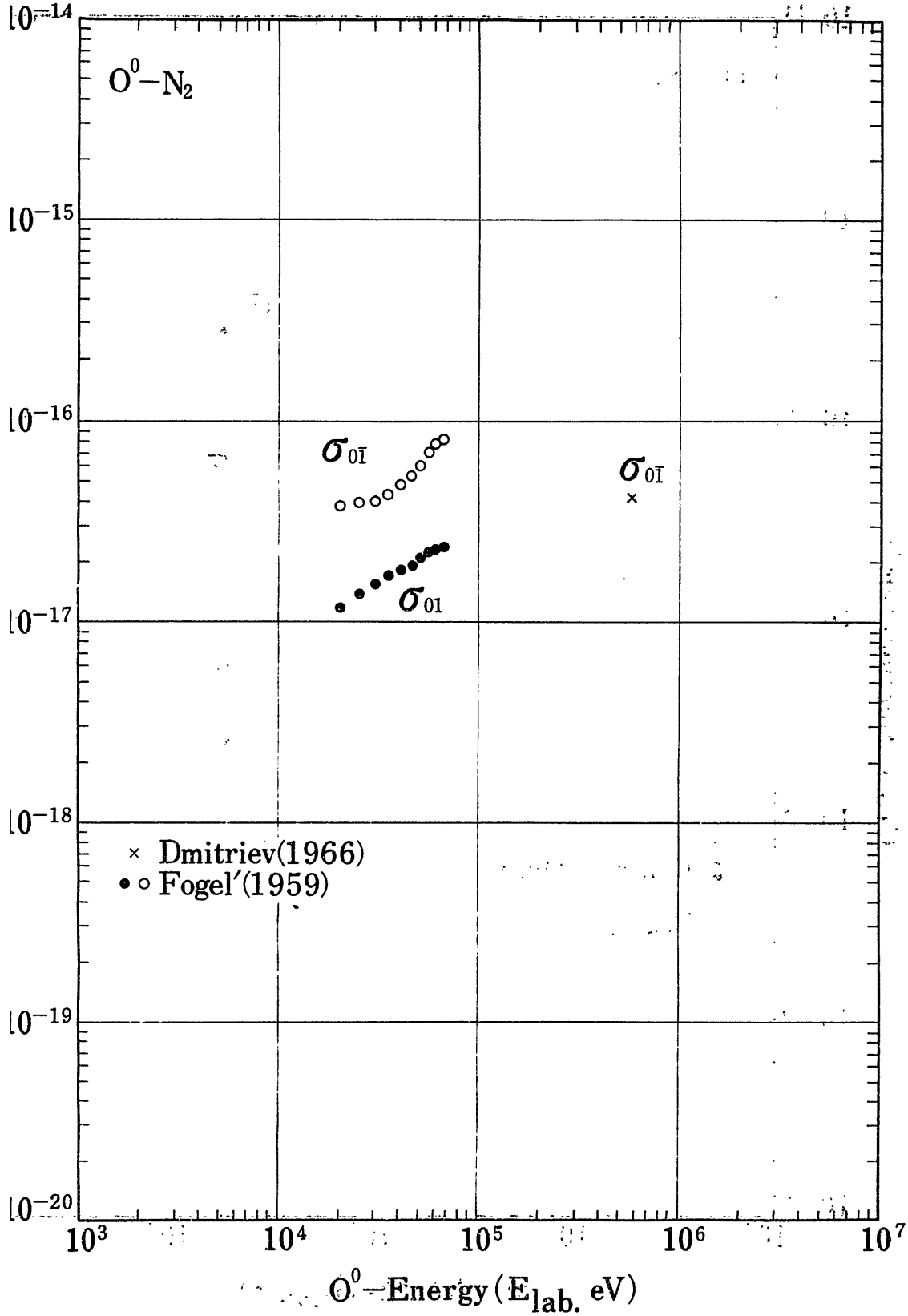


Fig.16 Charge Changing Cross Sections of O^0 in N_2

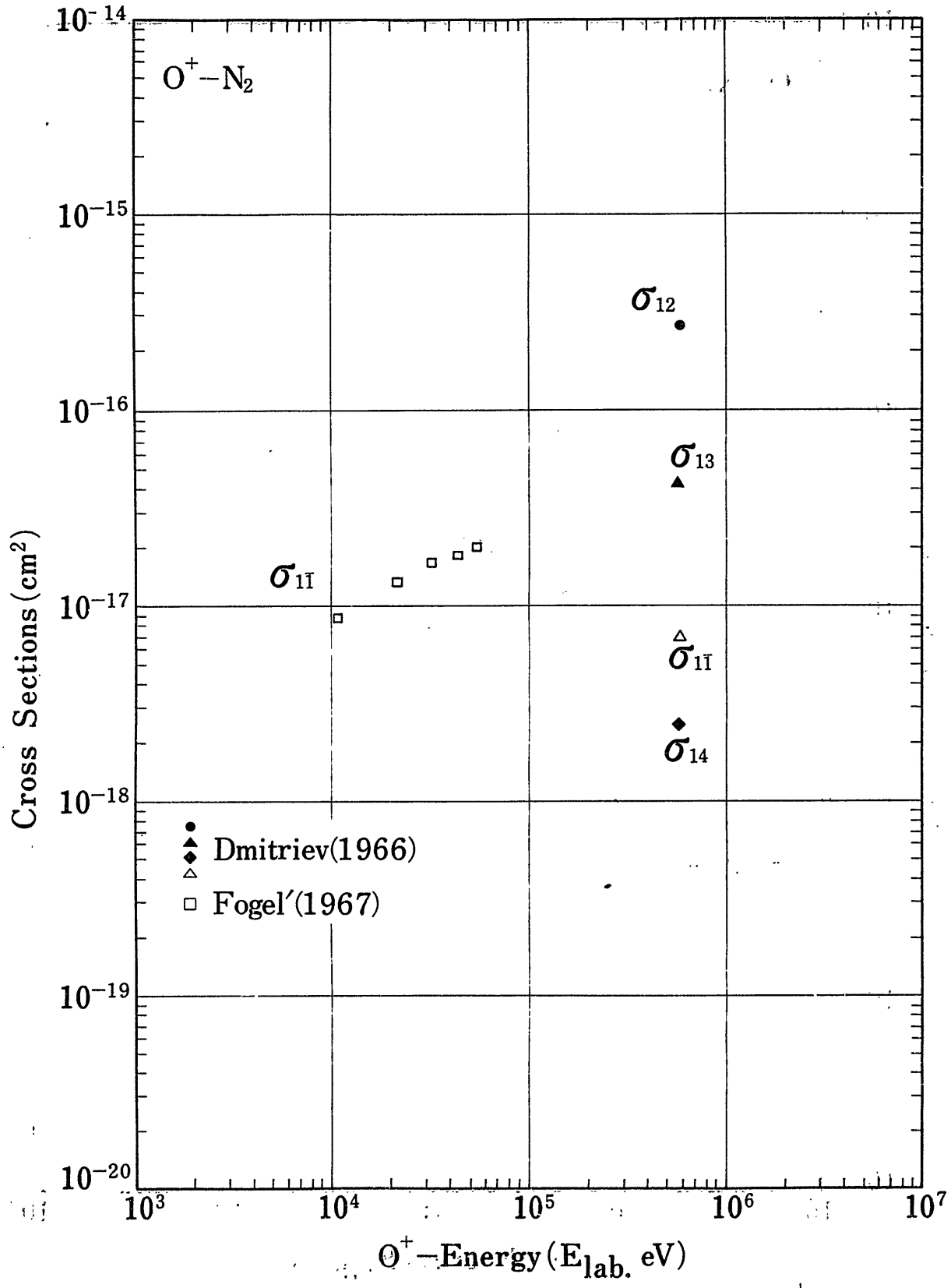


Fig.17 Charge Changing Cross Sections of O^+ in N_2

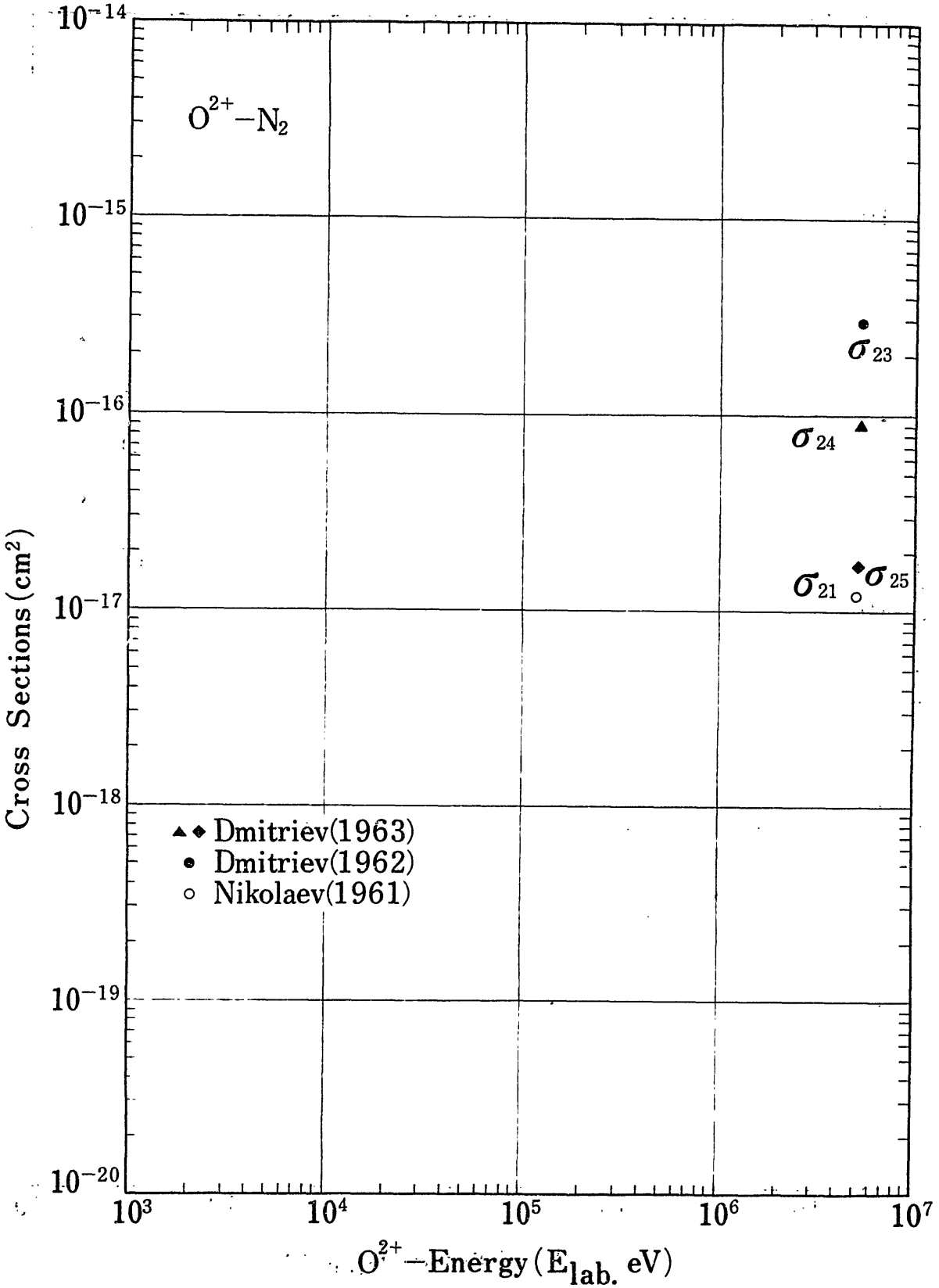


Fig.18 Charge Changing Cross Sections of O^{2+} in N_2

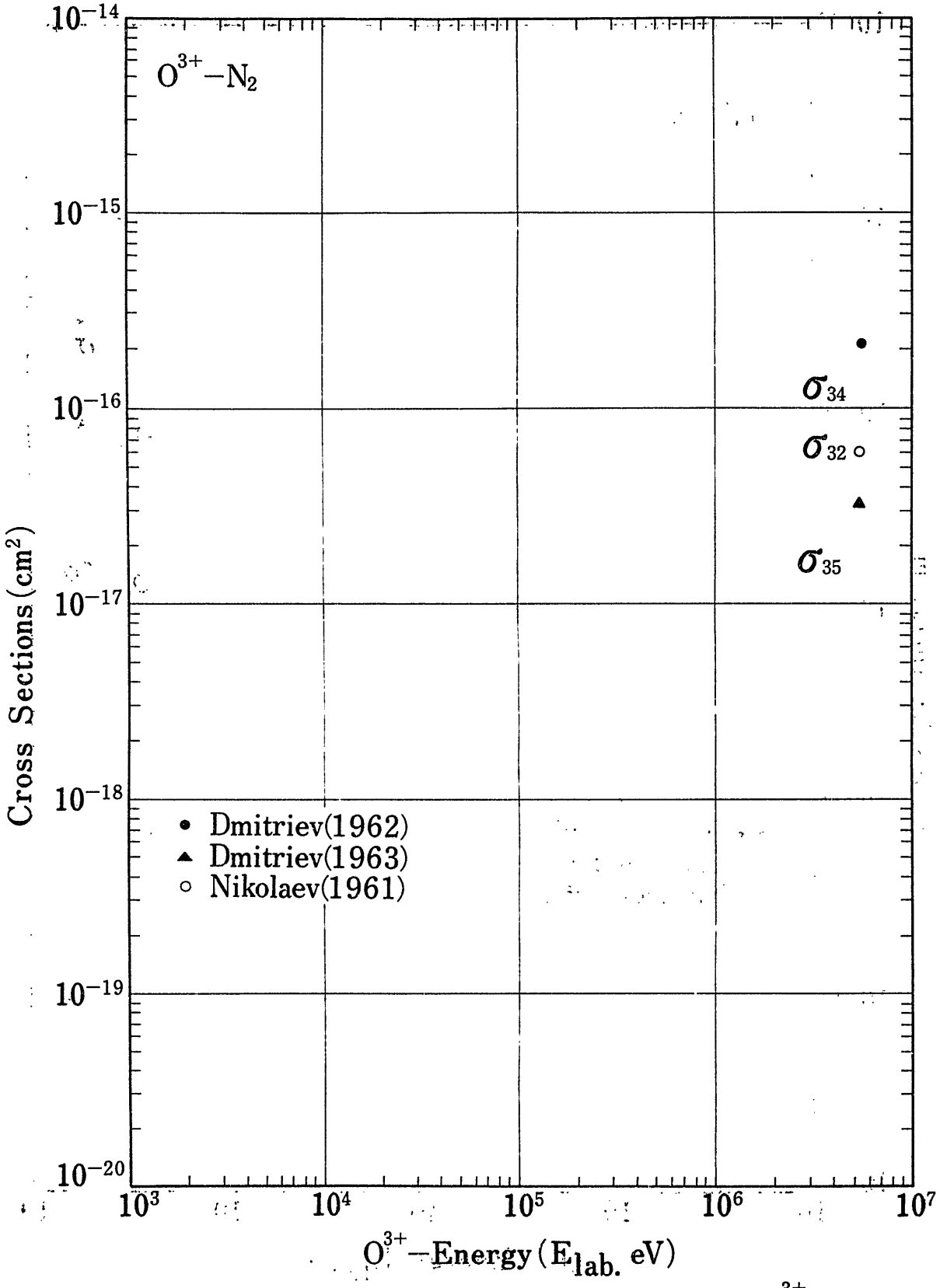


Fig.19 Charge Changing Cross Sections of O^{3+} in N_2

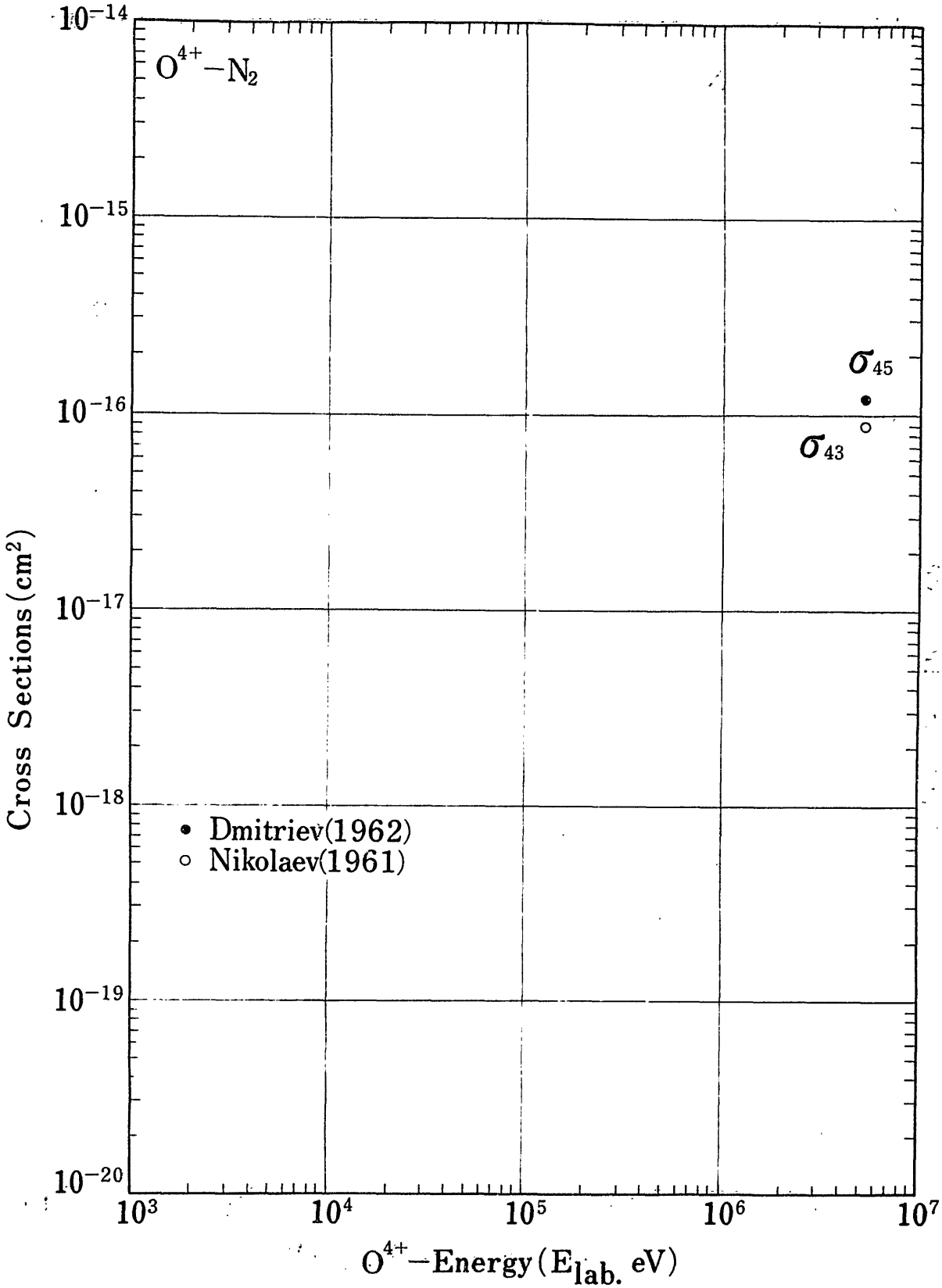


Fig. 20 Charge Changing Cross Sections of O^{4+} in N_2

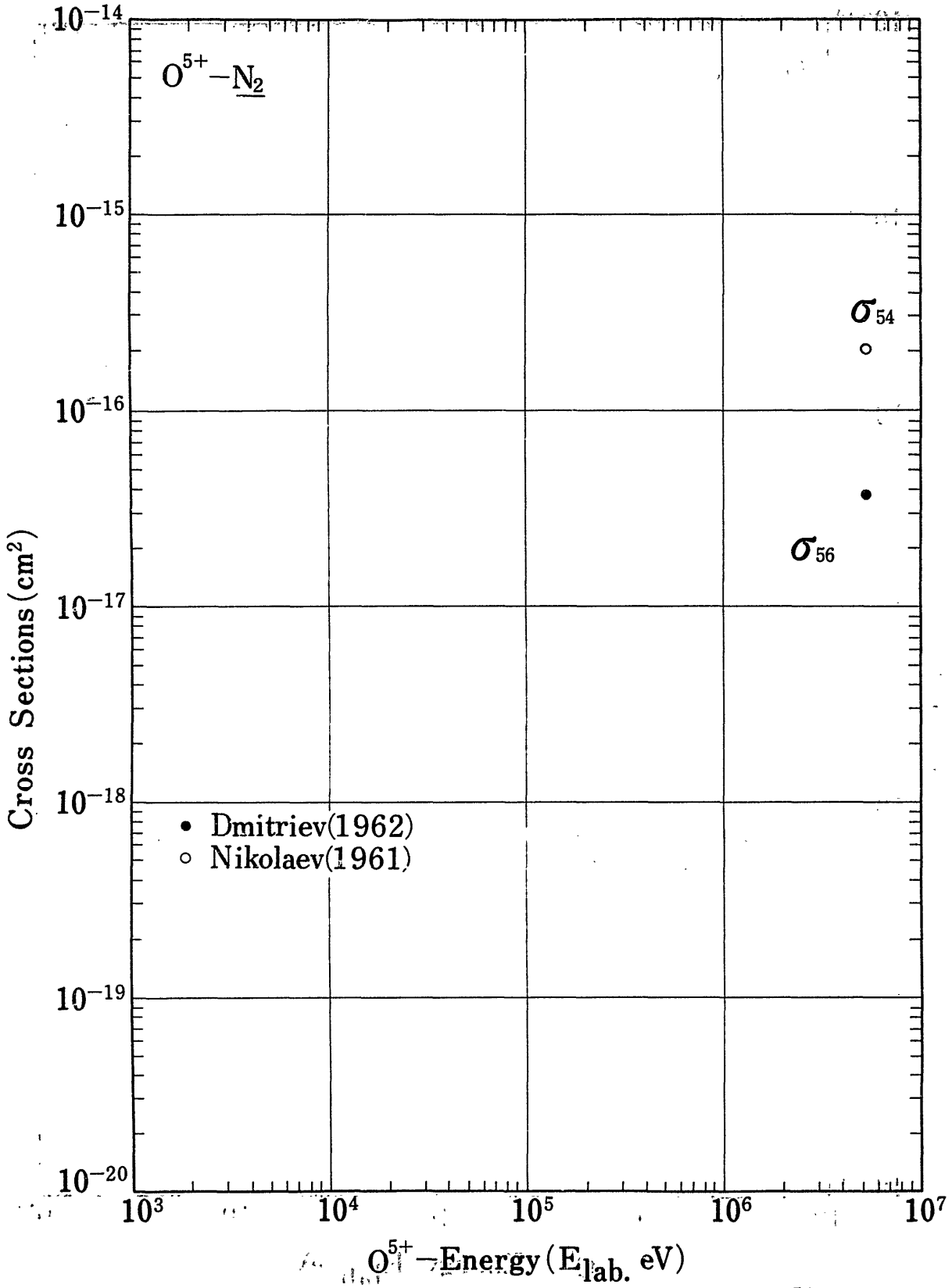


Fig. 21 Charge Changing Cross Sections of O^{5+} in N_2

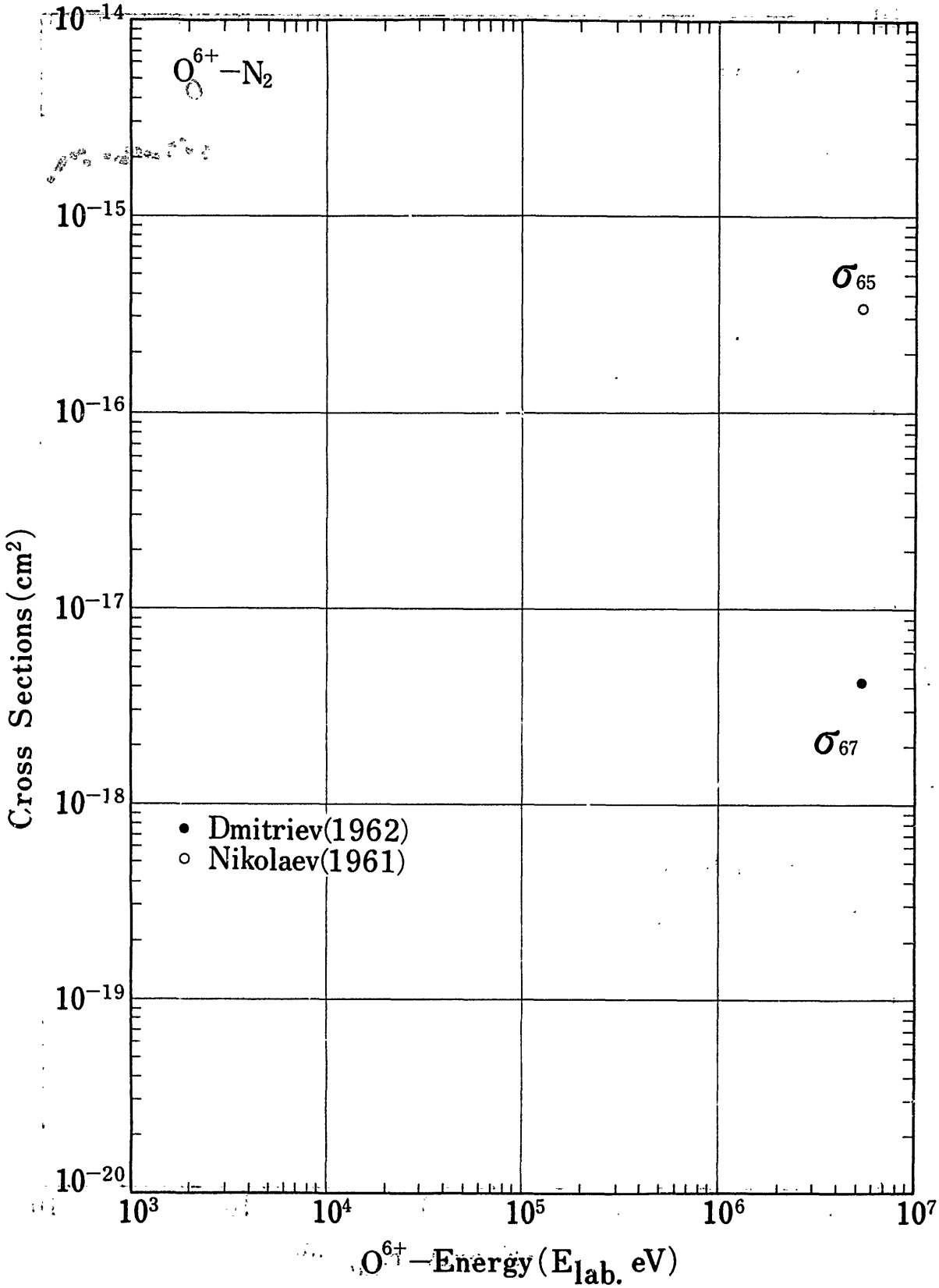


Fig.22 Charge Changing Cross Sections of O^{6+} in N_2

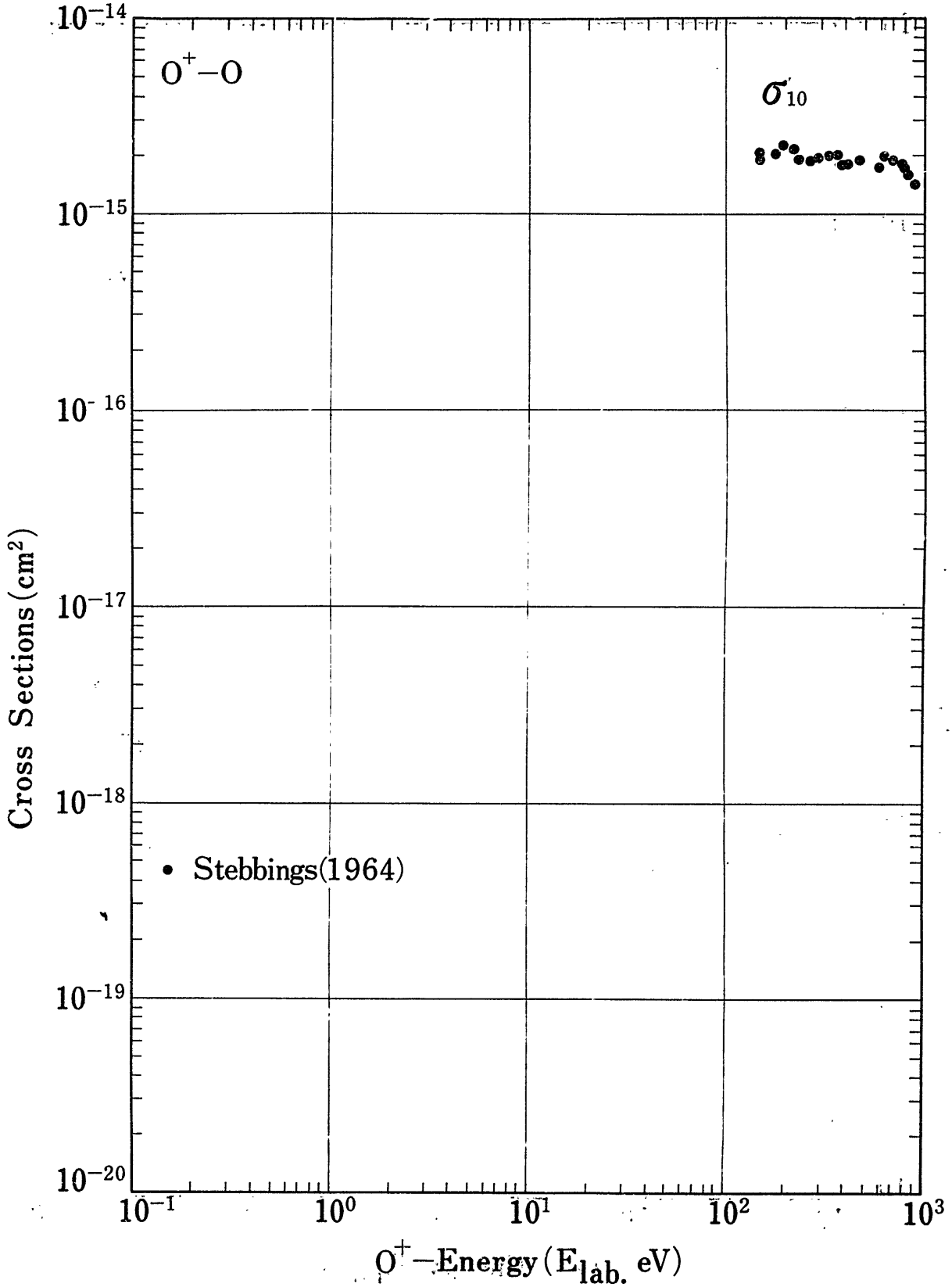


Fig.23—a Charge Changing Cross Sections of O^+ in O

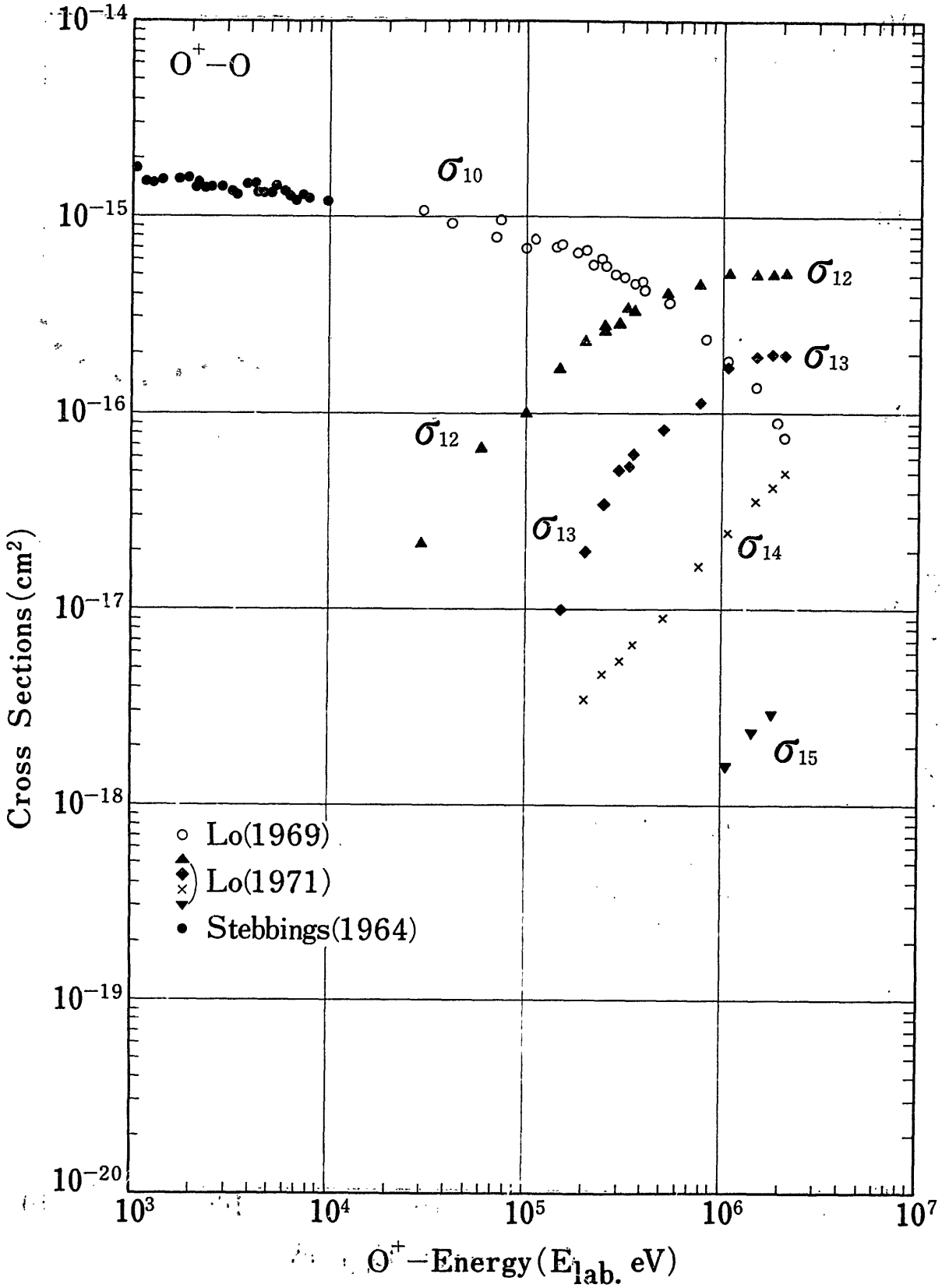


Fig.23-b Charge Changing Cross Sections of O^+ in O

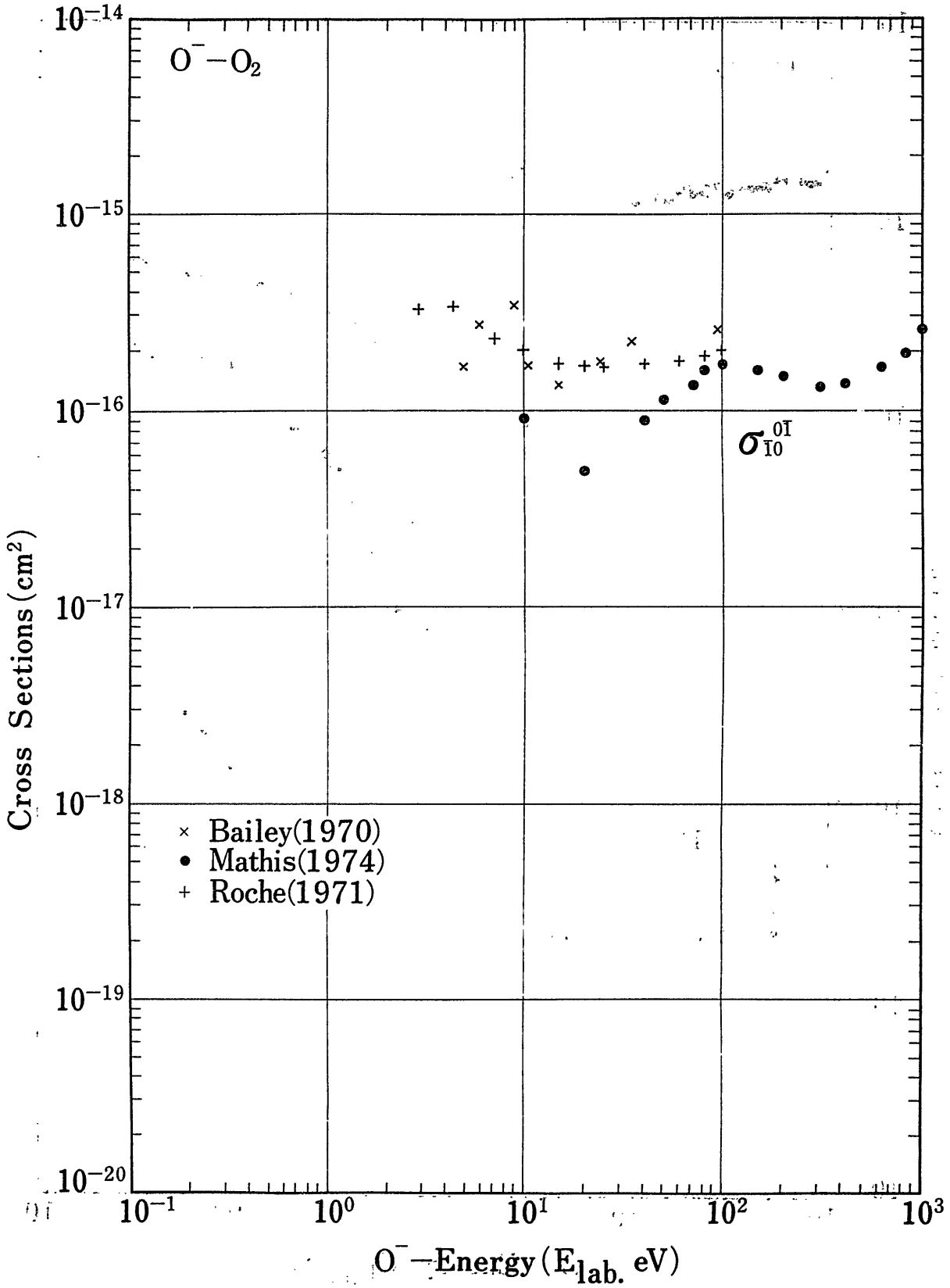


Fig.24—a Charge Changing Cross Sections of O^- in O_2

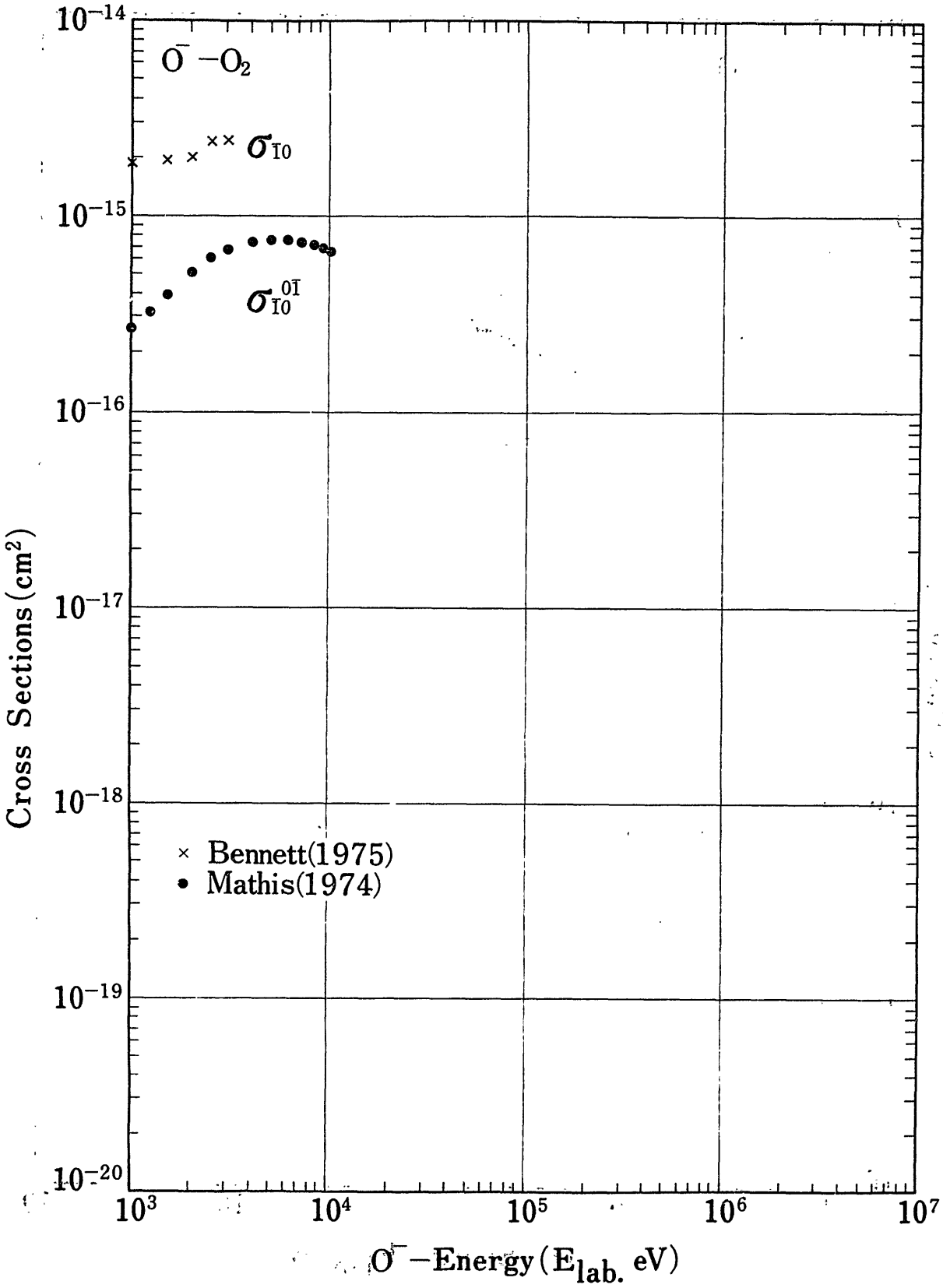


Fig.24−b Charge Changing Cross Sections of O^- in O_2

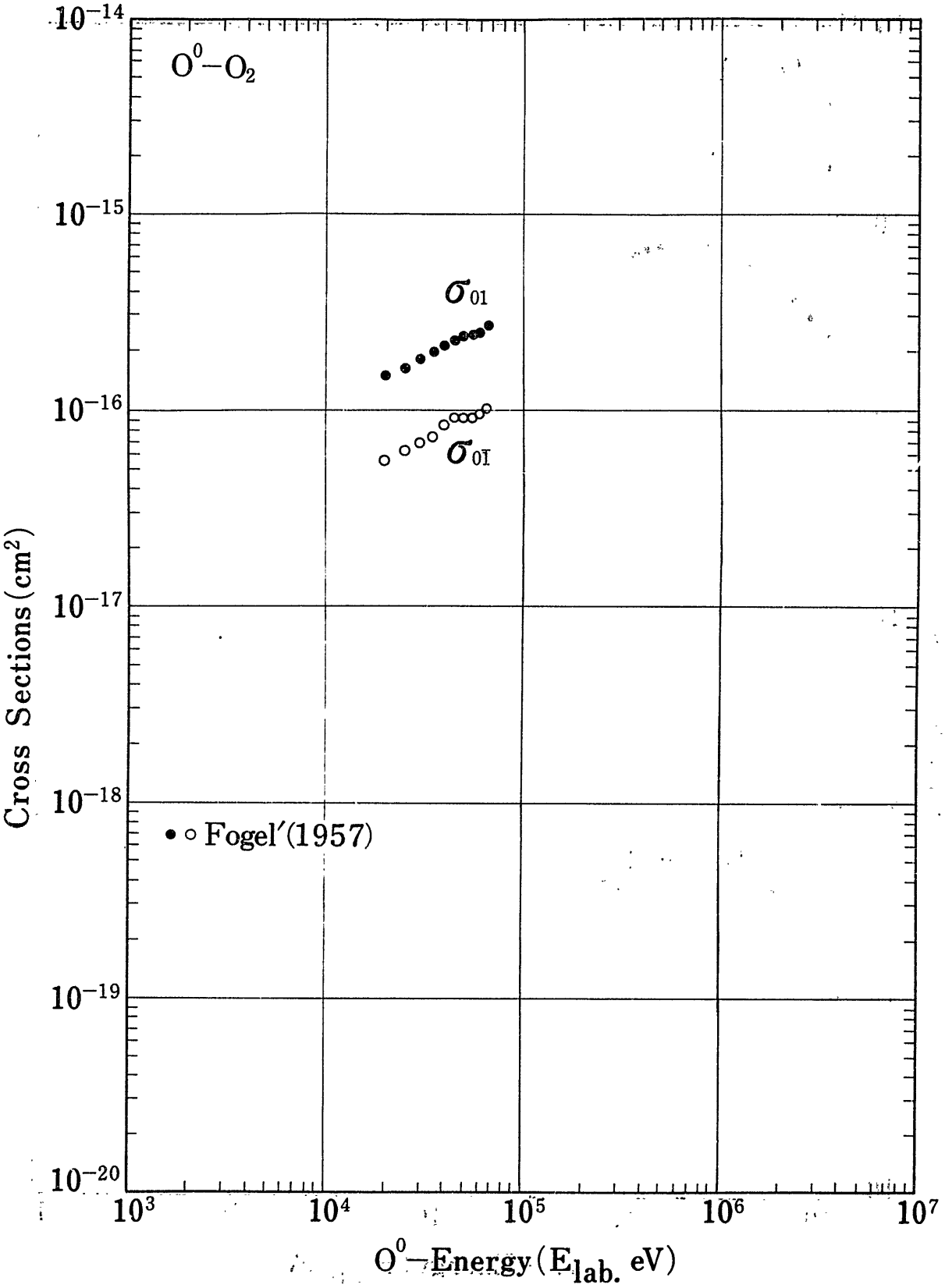


Fig.25 Charge Changing Cross Sections of O^0 in O_2

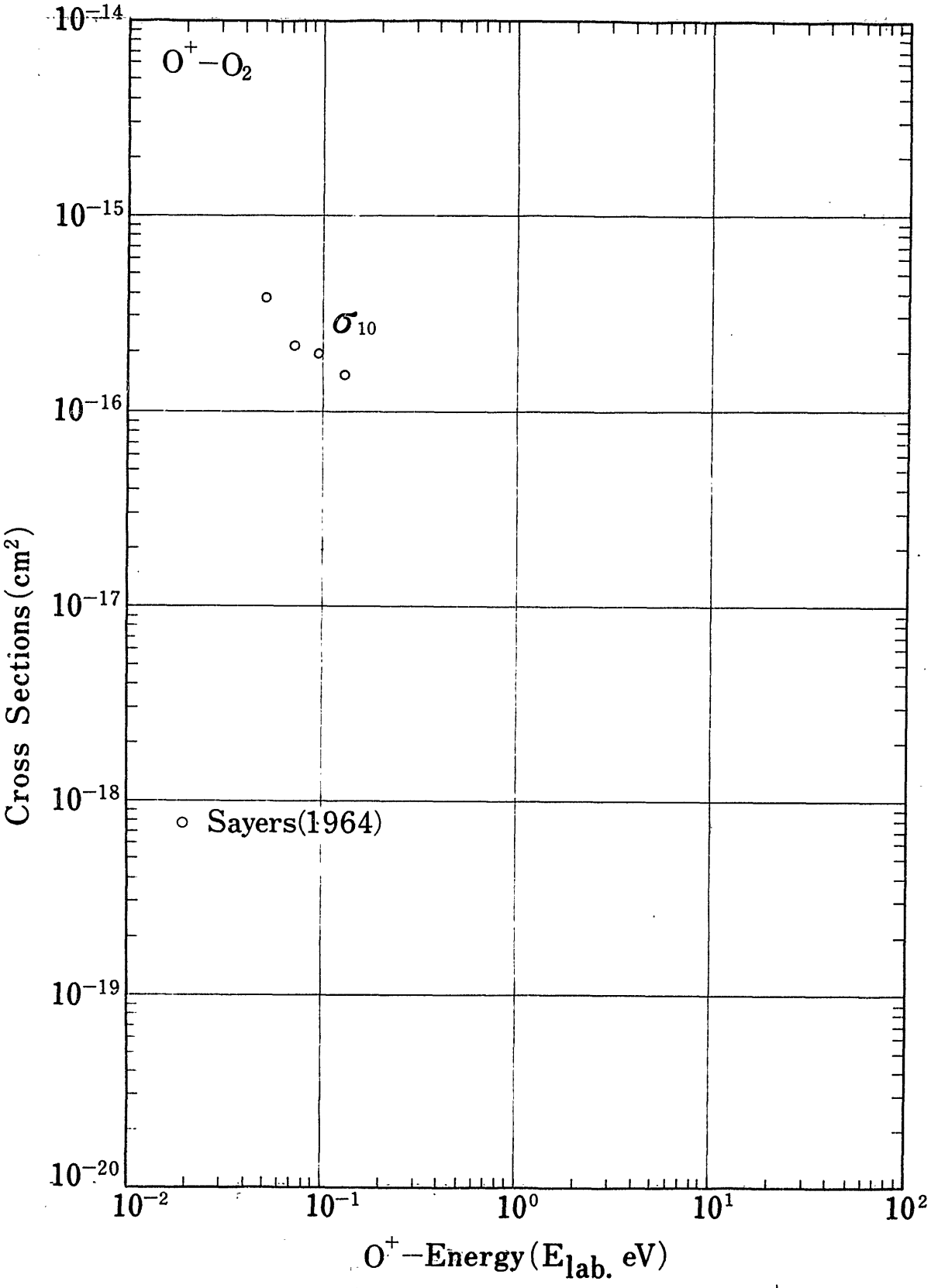


Fig.26 Charge Changing Cross Sections of O^+ in O_2

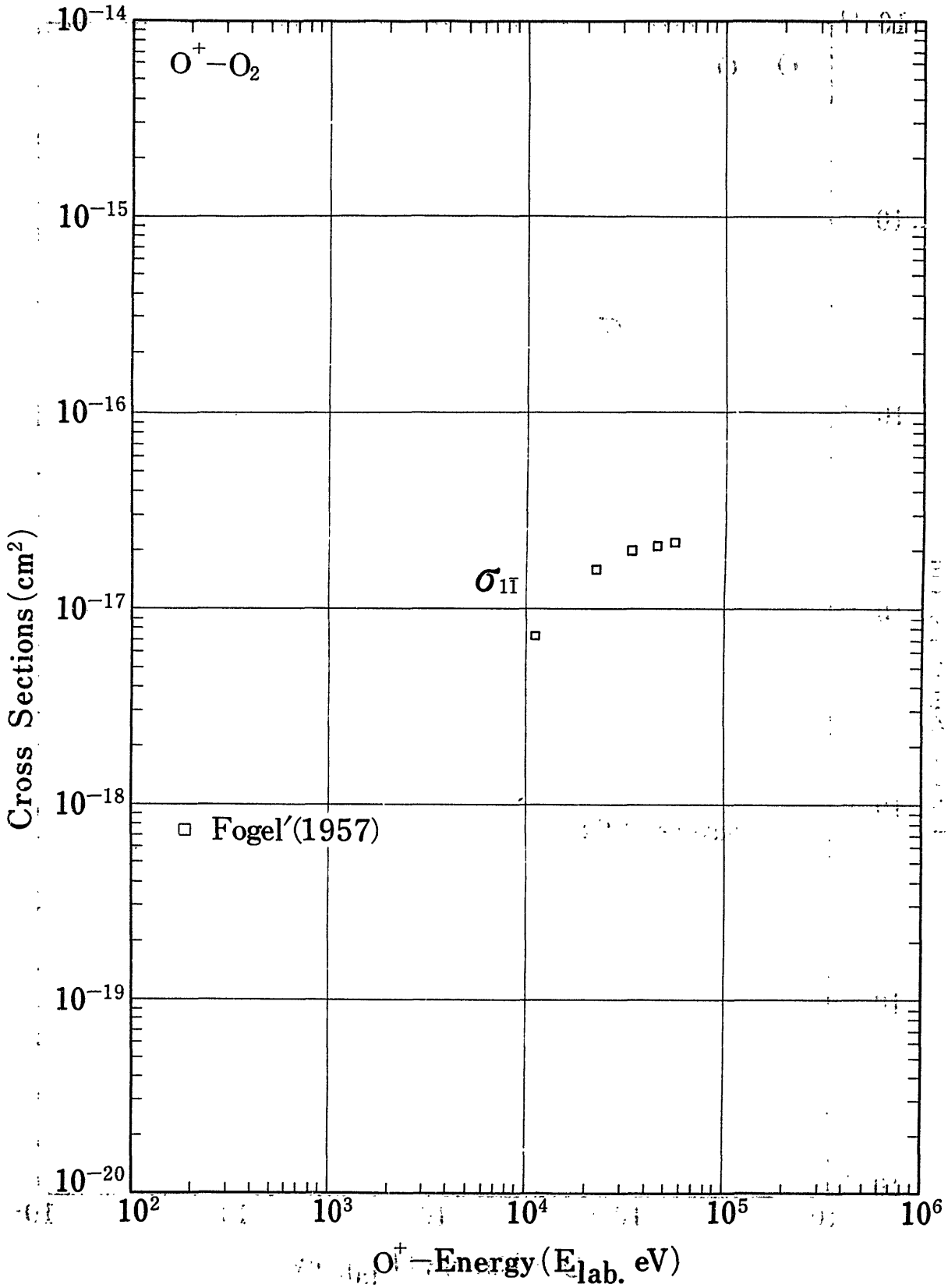


Fig.27 Charge Changing Cross Sections of O^+ in O_2

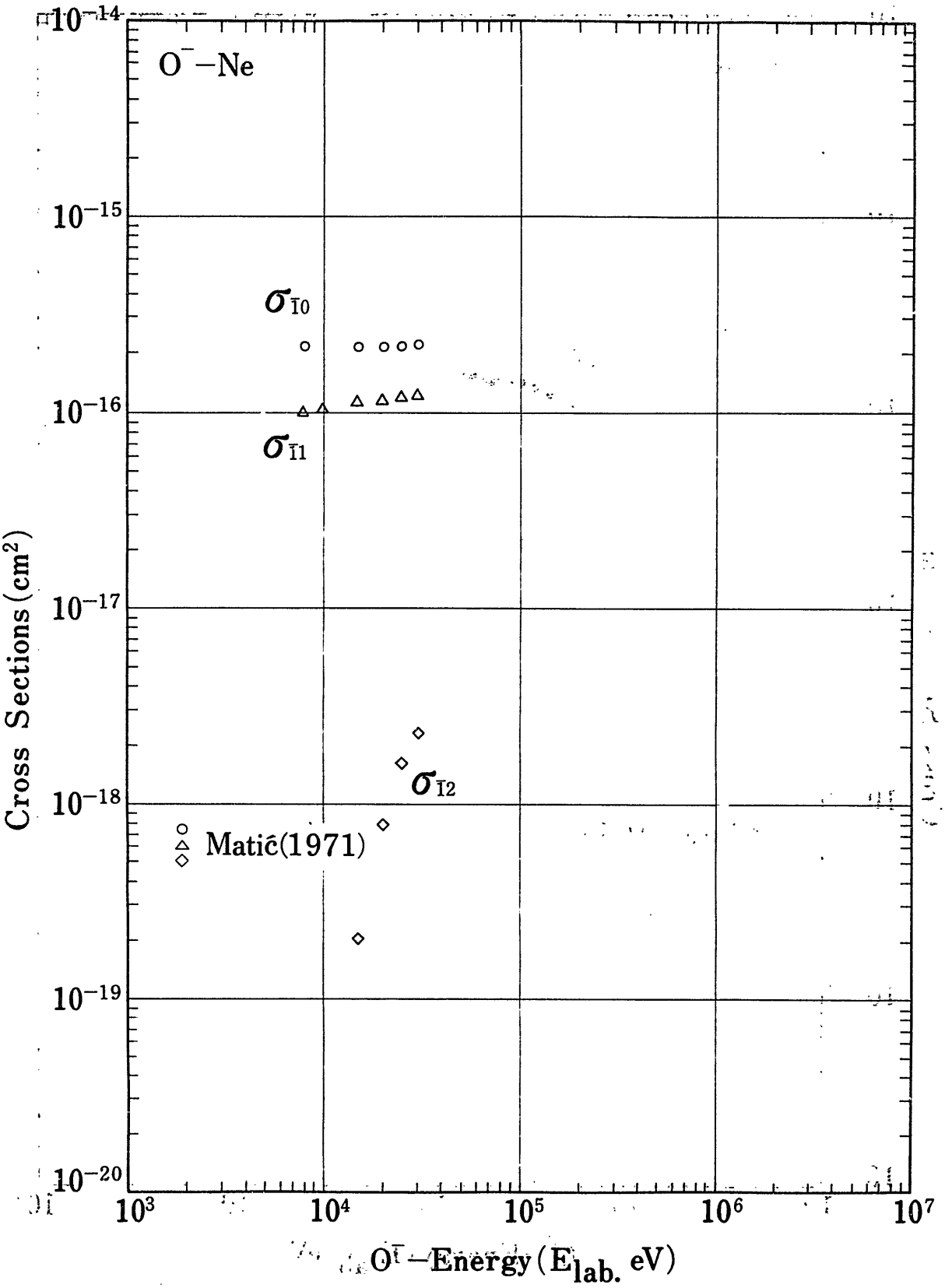


Fig.28 Charge Changing Cross Sections of O^- in Ne

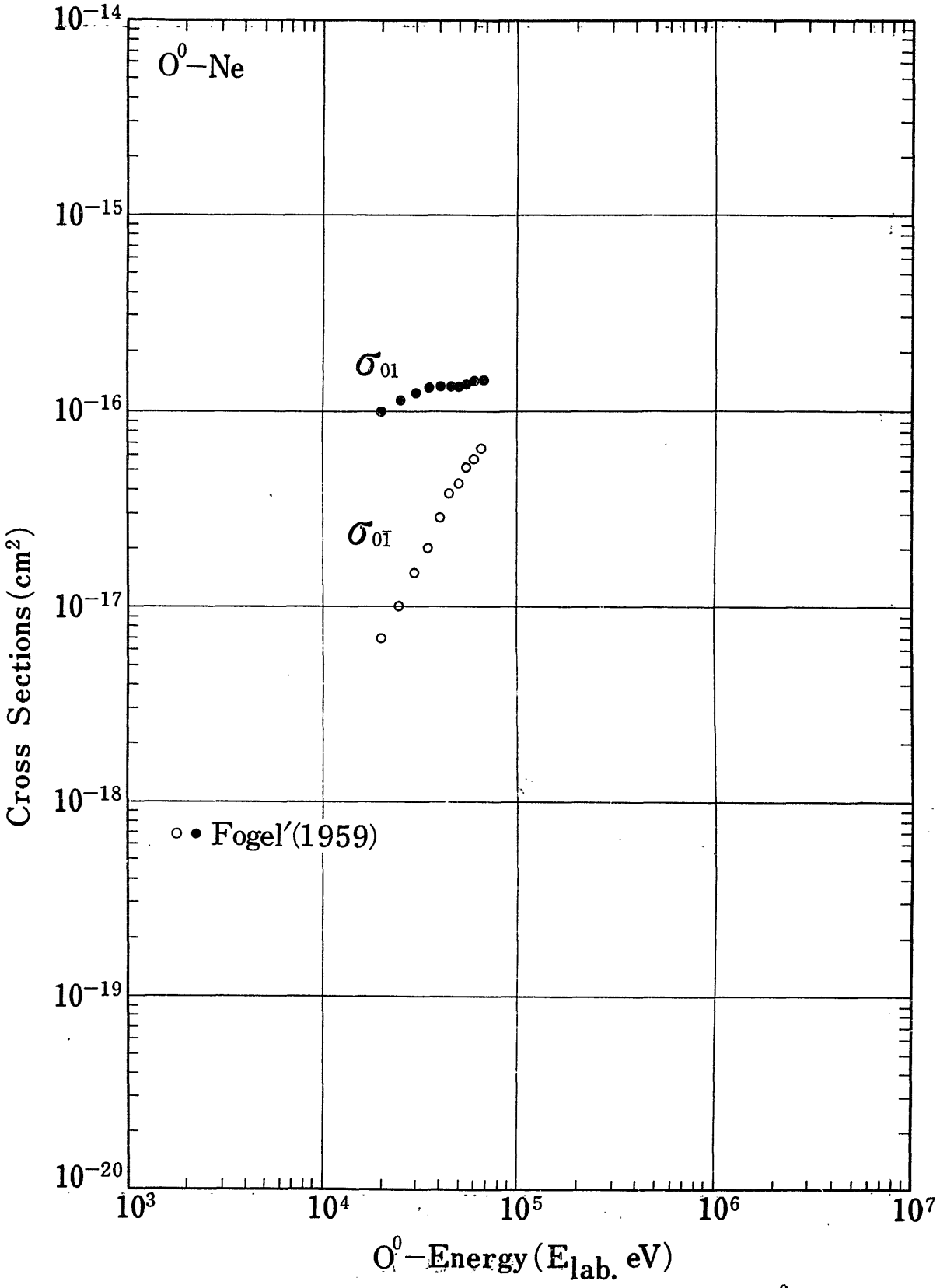


Fig.29 Charge Changing Cross Sections of O^0 in Ne

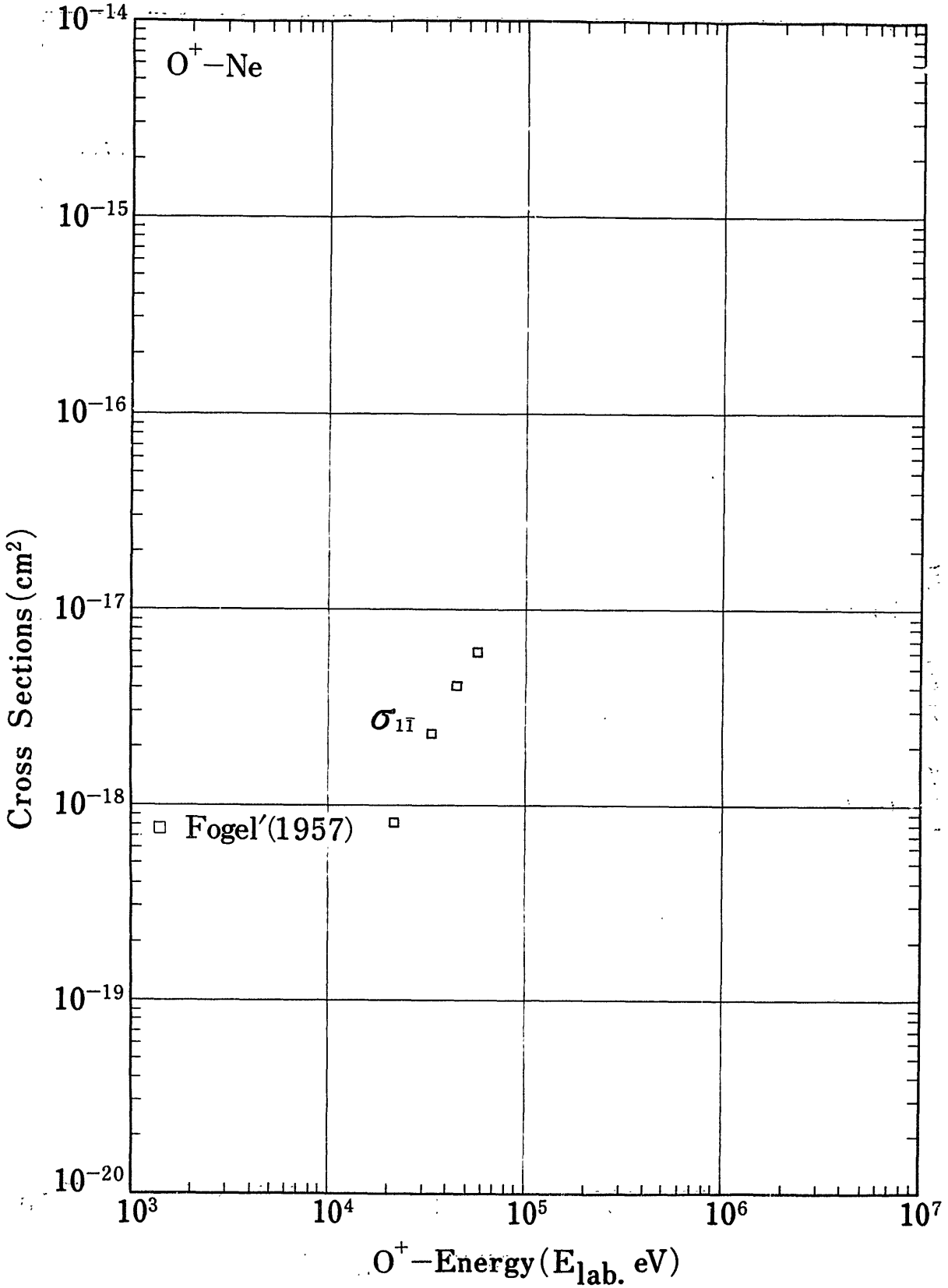


Fig. 30 Charge Changing Cross Sections of O^+ in Ne

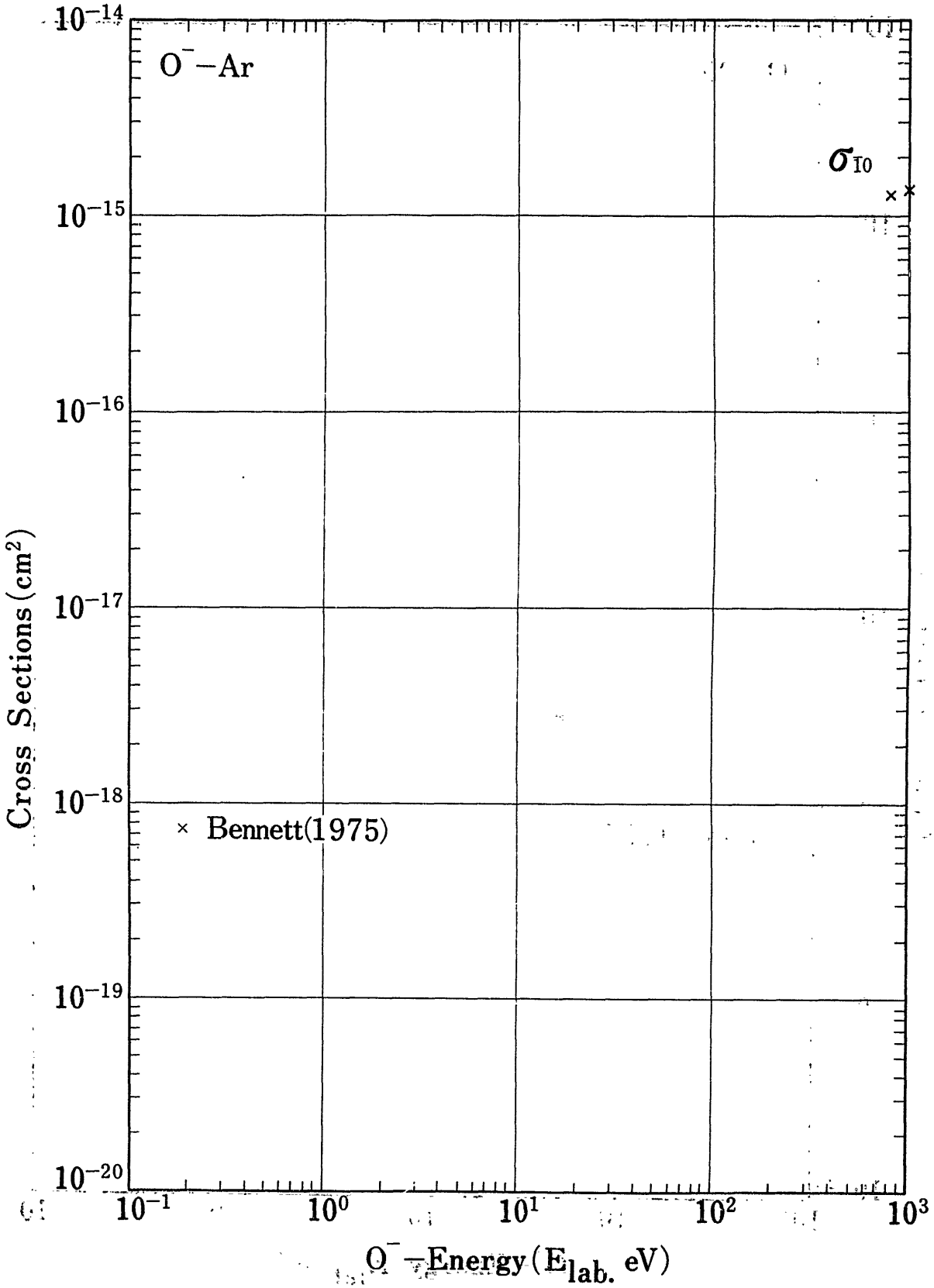


Fig. 31−a Charge Changing Cross Sections of O^- in Ar

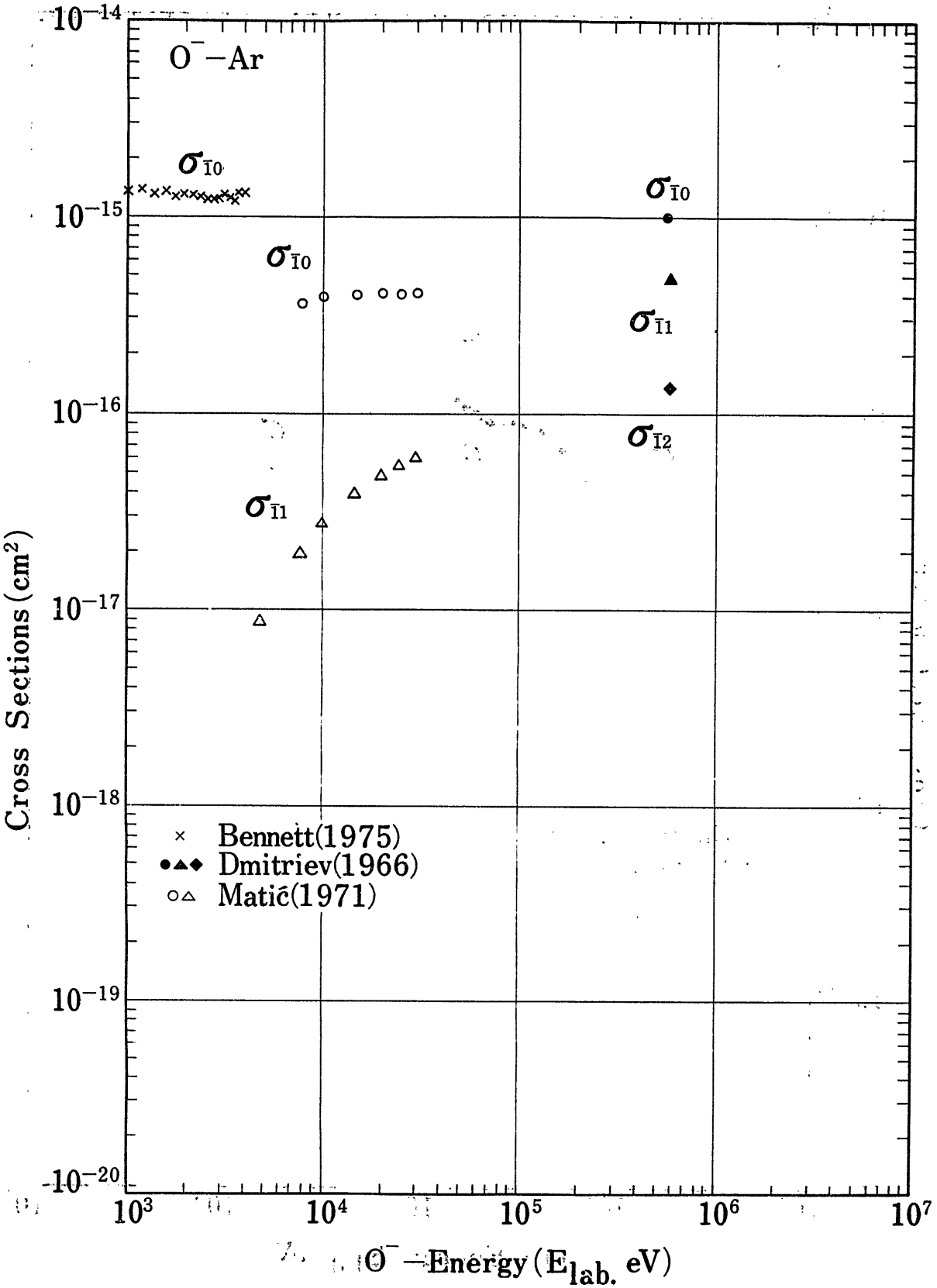


Fig.31—b Charge Changing Cross Sections of O^- in Ar

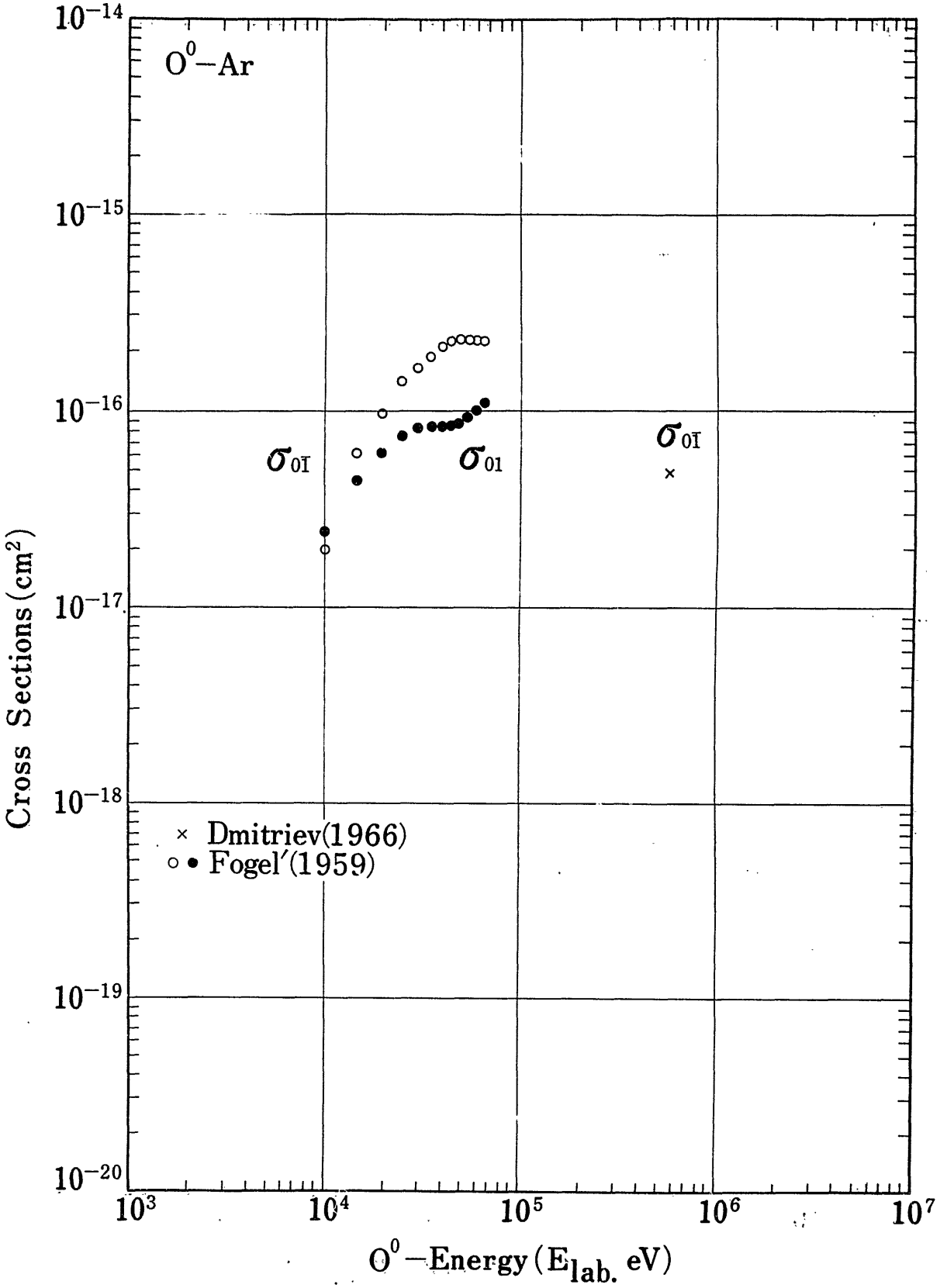


Fig.32 Charge Changing Cross Sections of O^0 in Ar

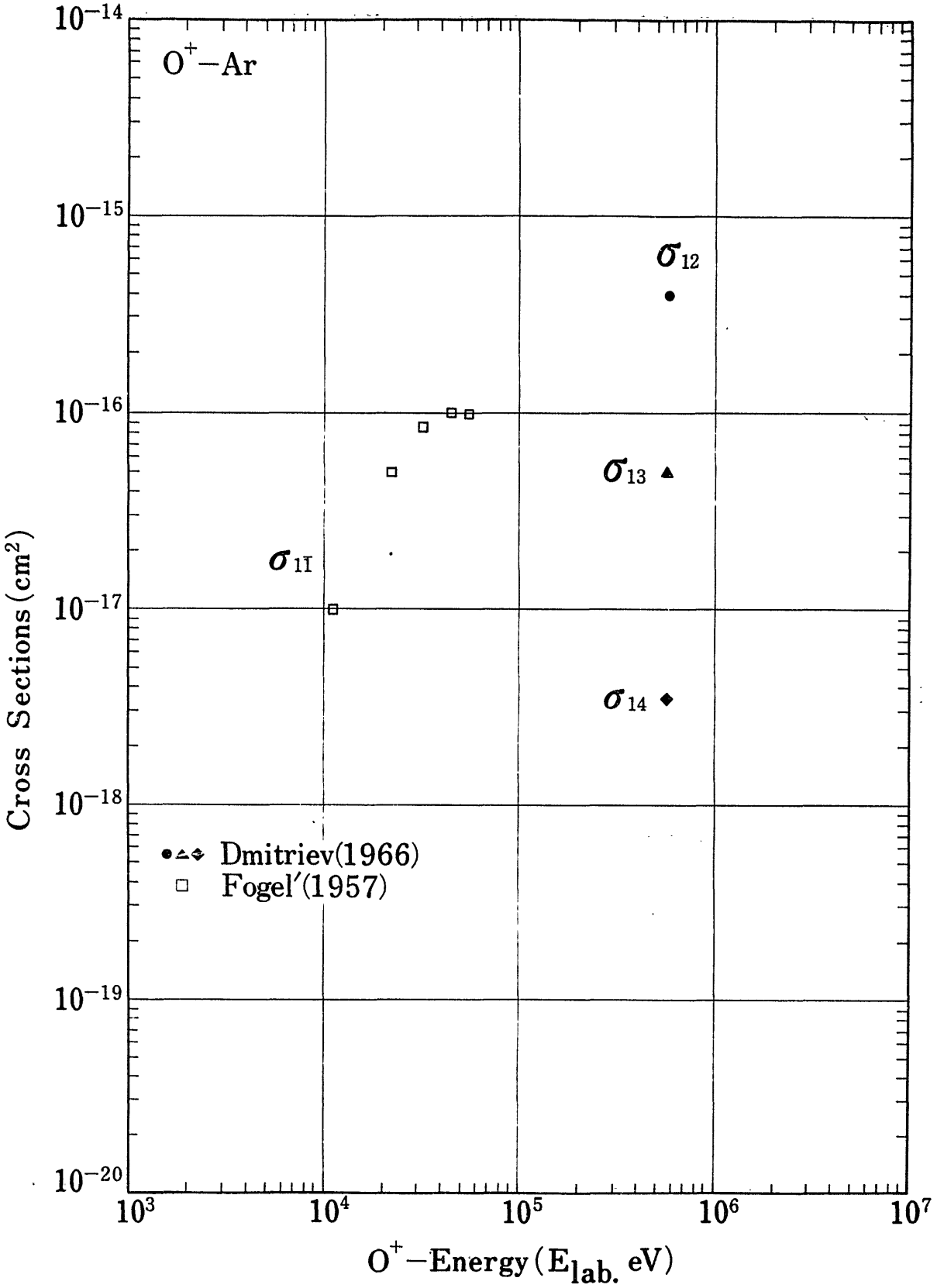


Fig.33 Charge Changing Cross Sections of O^+ in Ar

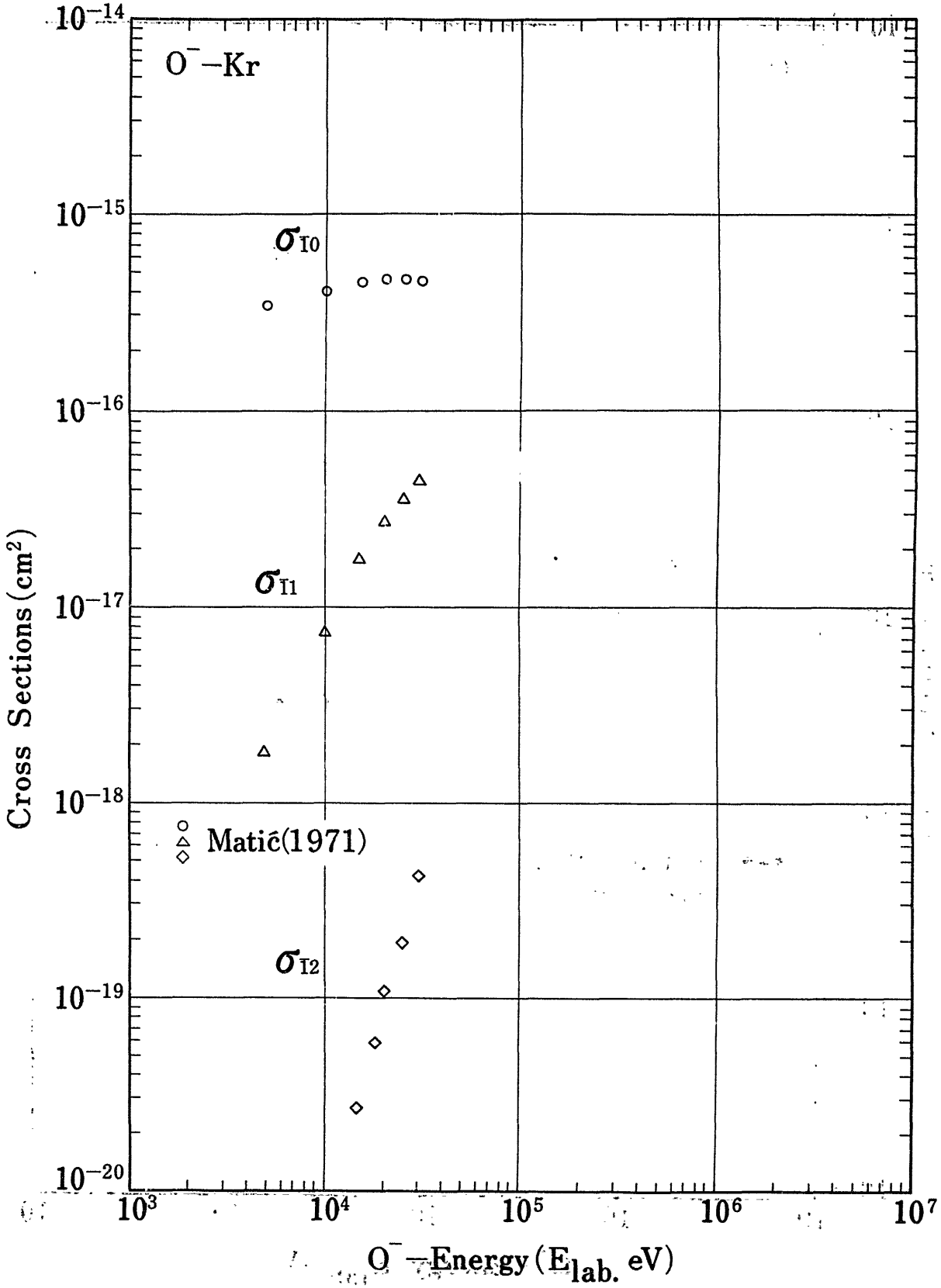


Fig. 34 Charge Changing Cross Sections of O^- in Kr

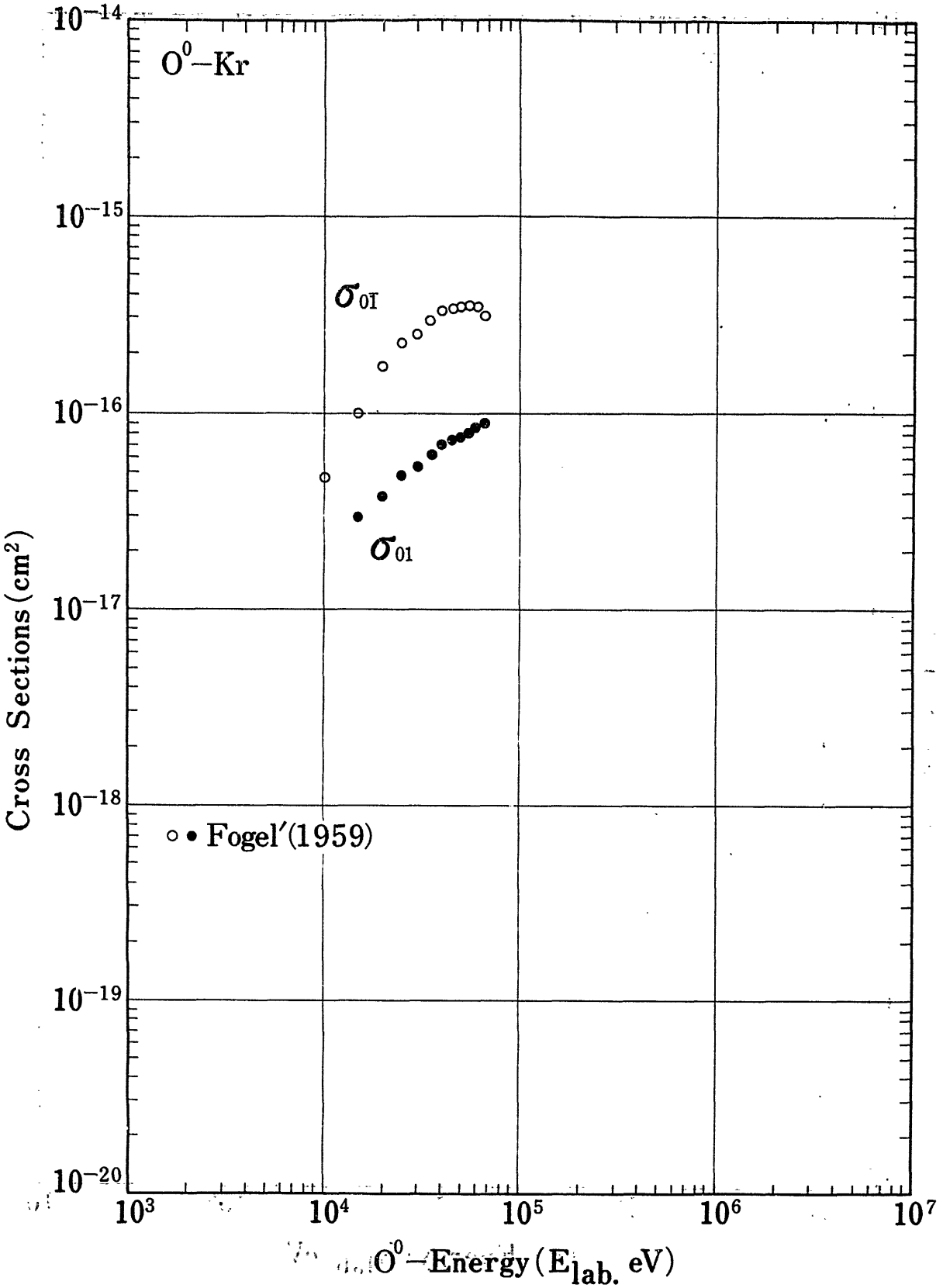


Fig.35 Charge Changing Cross Sections of O^0 in Kr

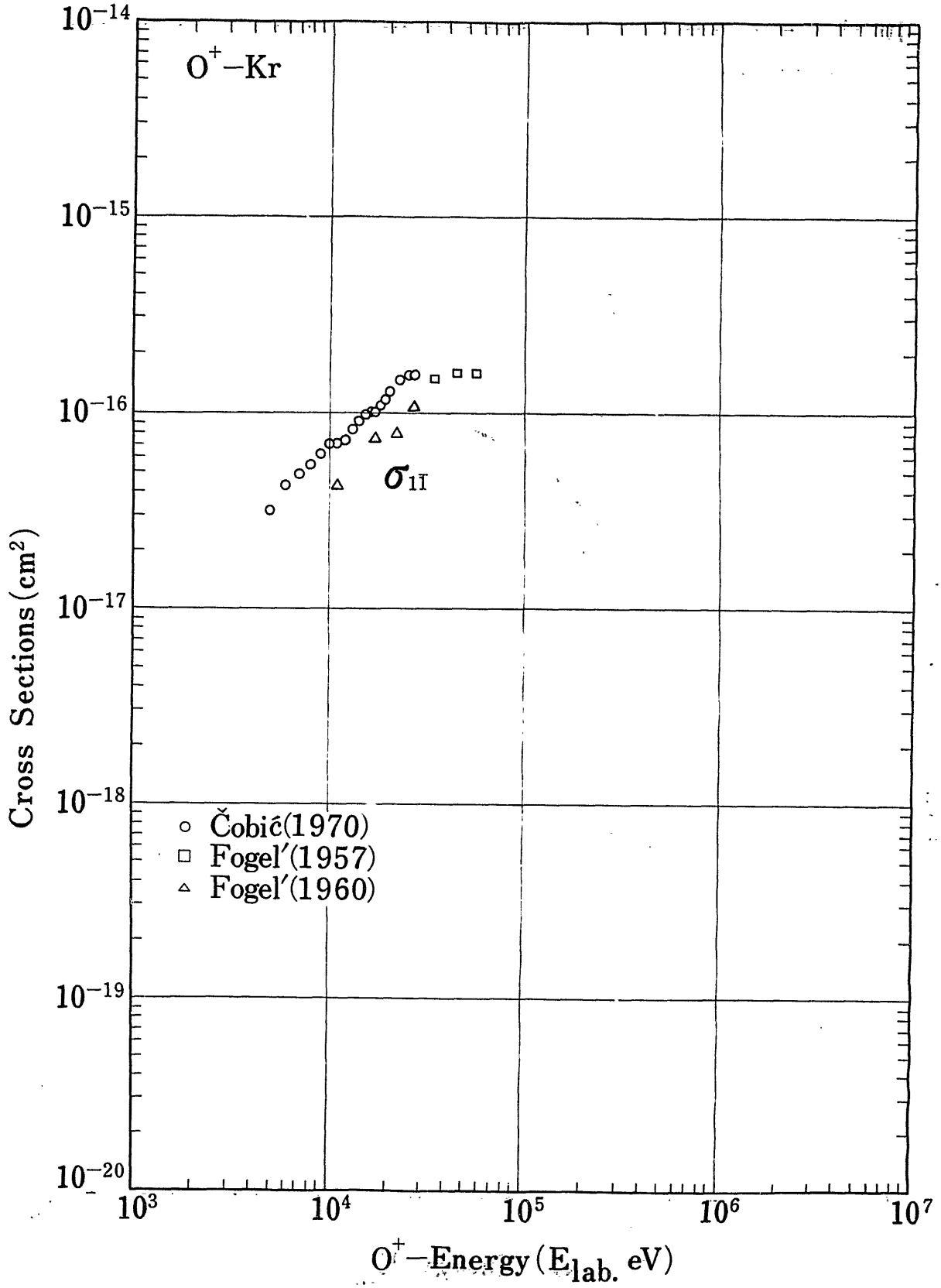


Fig.36 Charge Changing Cross Sections of O^+ in Kr

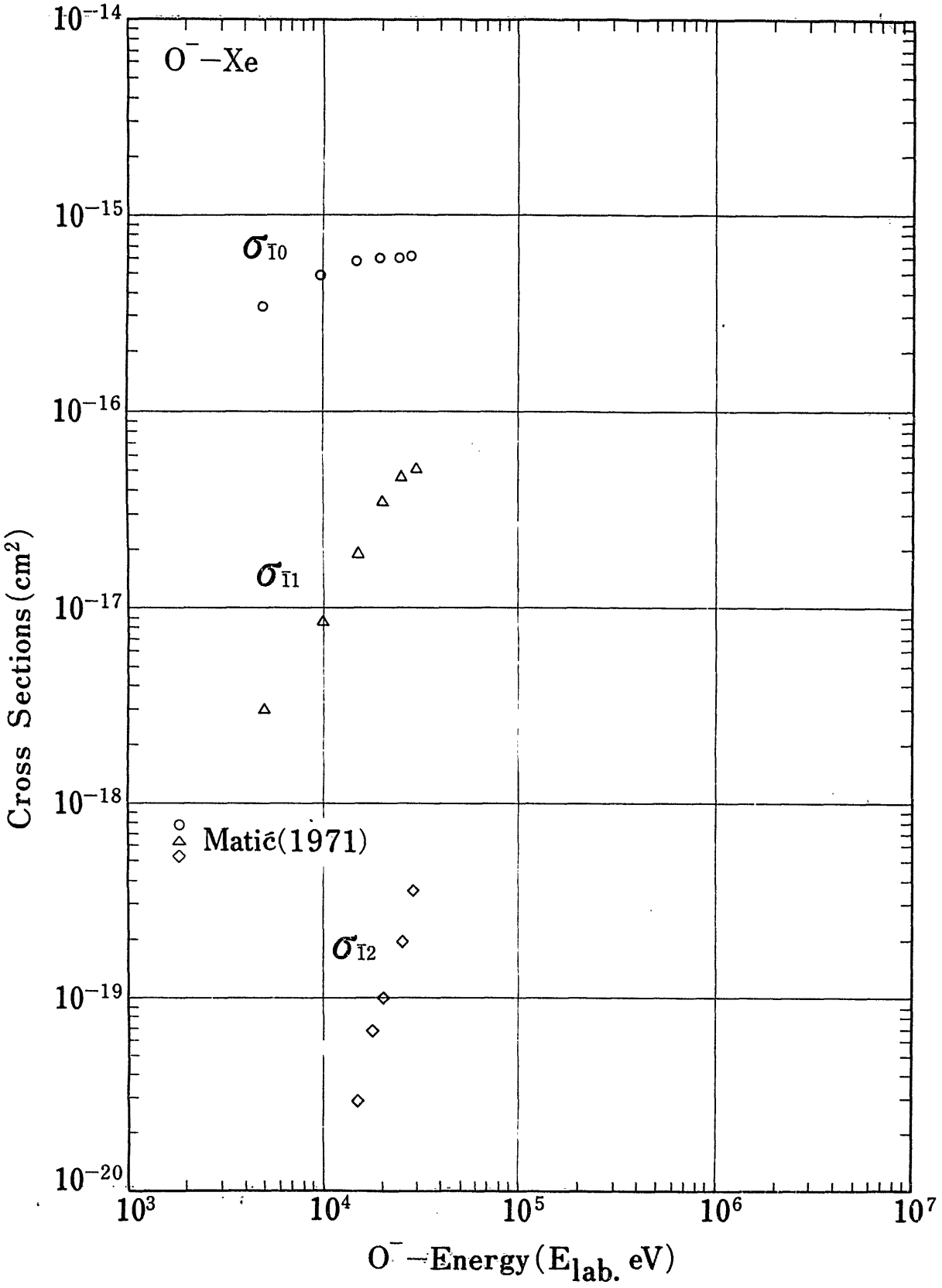


Fig. 37 Charge Changing Cross Sections of O^- in Xe

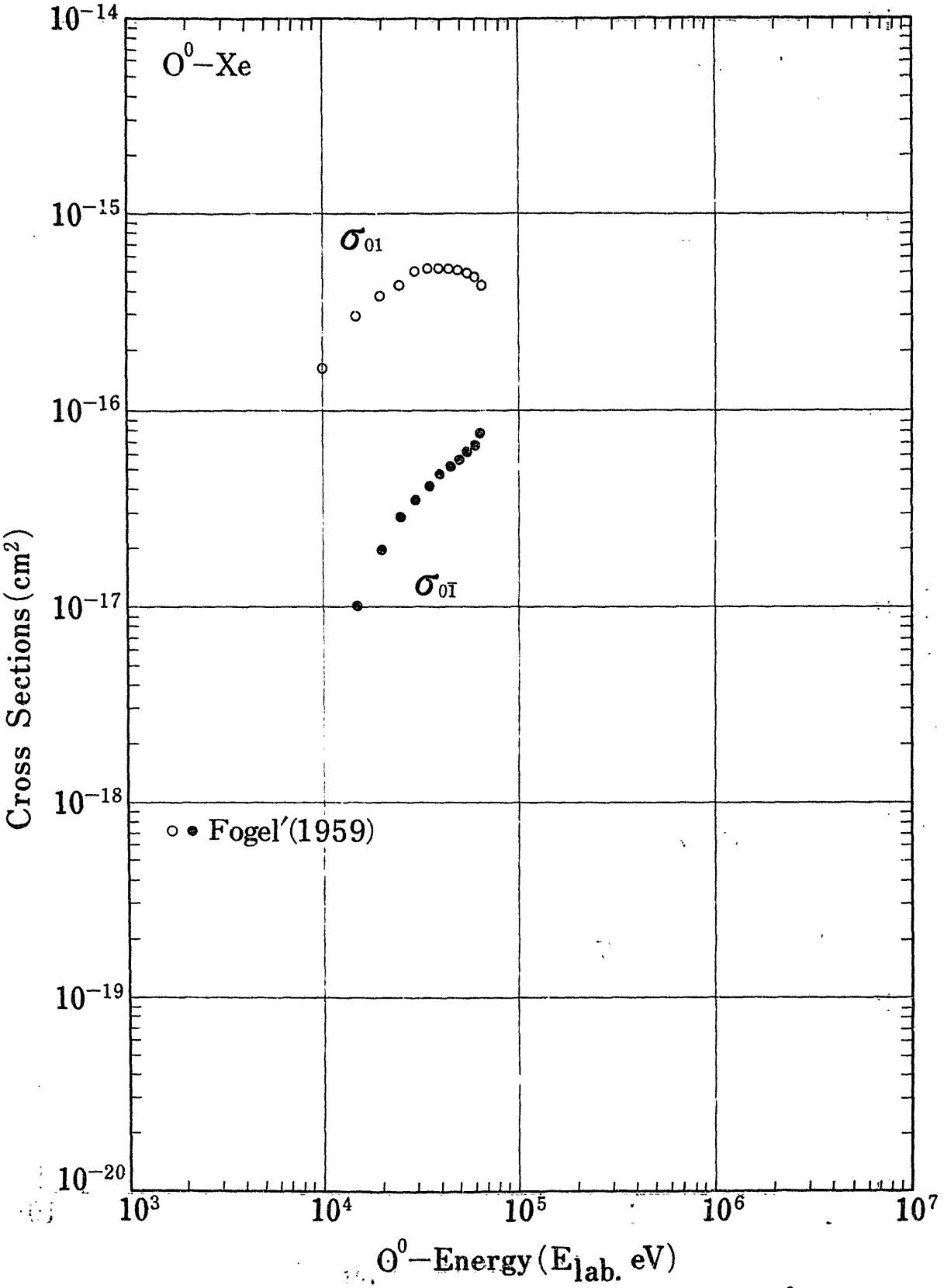


Fig.38 Charge Changing Cross Sections of O^0 in Xe

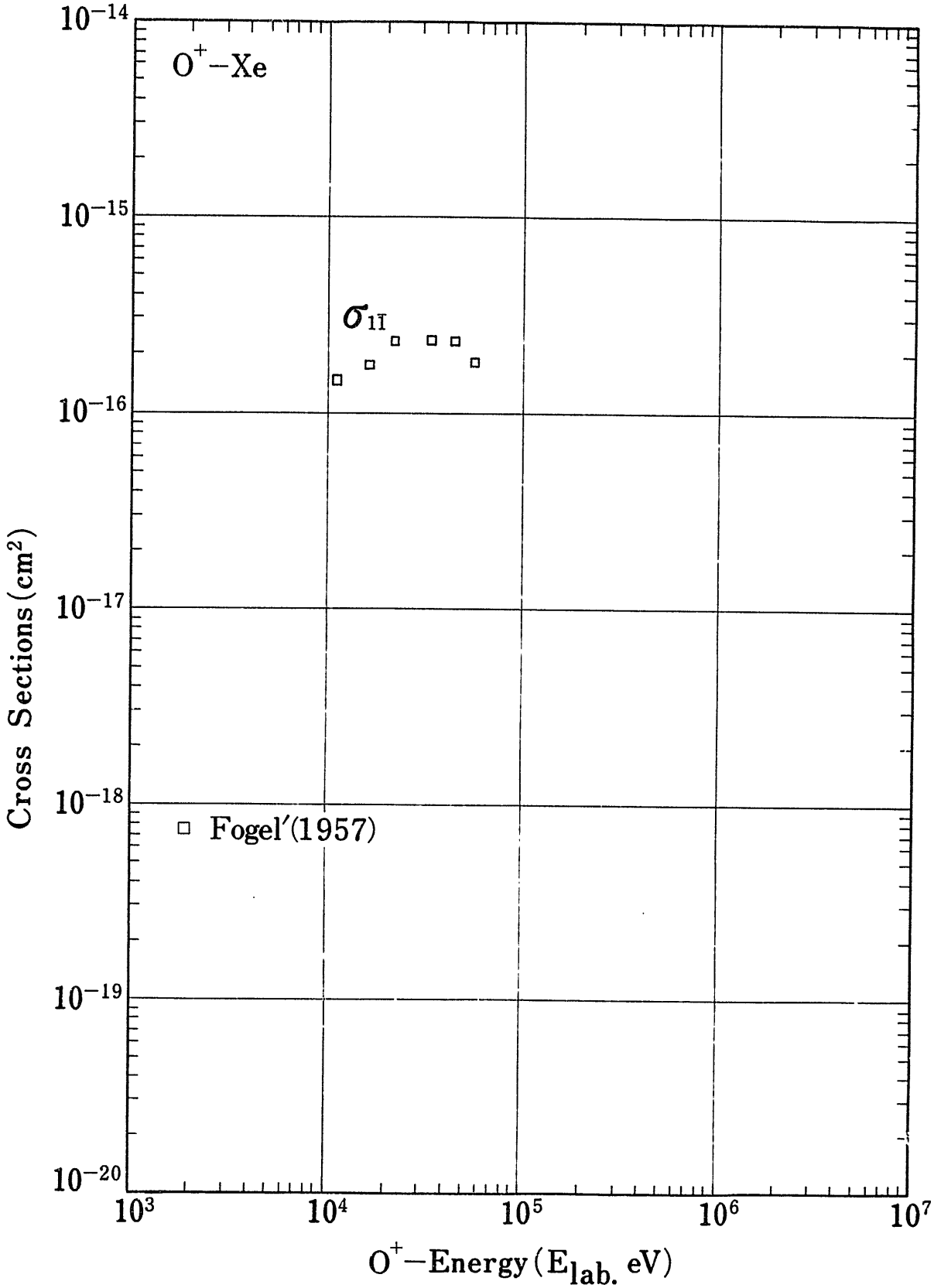


Fig.39 Charge Changing Cross Sections of O^+ in Xe