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RECENT WORK ON STELLAR INTERIORS:
A BIBLIOGRAPHY OF MATERIAL PUBLISHED BETWEEN
1958 AND MID-1966

prepared by

Edward Langer, Margaret Herz, and J. P. Cox

NOTICE

This report is NOT being published in any other form.

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INTRODUCTION

This bibliography of recently published material on stellar interiors and closely related subjects has been compiled in the hope that it might be useful to students and workers in the field. Since the review article on stellar evolution by Burbidge and Burbidge* contains a comprehensive bibliography on the relevant literature published before 1958, this report lists only articles (834) published between 1958 and mid-1966. Section I is the only exception. It contains most of the significant books (in the English language) relevant to the general problem of stellar interiors published to date.

The articles are listed alphabetically by author (by the first author in cases of multiple authorship, and by date in cases of several articles by the same first author) in several different categories. Each paper (with the exception of the paper by Hayashi, Hoshi, and Sugimoto (1962)) is entered only once despite the fact that many entries might have been properly fitted into more than one category. This makes the report shorter—and, unfortunately, a few things more difficult to find.

The mass, initial composition, construction technique, equation(s) of state, modes of energy transport, and kinds of energy sources included are summarized briefly for each stellar interior model that was actually constructed. A table of these models, arranged by mass and composition,

appears in the appendix. In general, the notation employed here follows conventional usage in stellar interior studies.* In particular, the X, Y, and Z that appear in the stellar model summaries are the usual fractional mass abundances of hydrogen, helium, and "heavy elements," respectively. Evolving models are designated by an (E). Only the title of the paper and a reference to the journal in which it appears is included for all other entries.

A list of abbreviations used in this report for the titles of journals is given immediately following this introduction.

The present bibliography was not intended to be complete, and some of the less readily available journals have not been searched. Essentially all of the articles entered in this report are written in English, French or German. We hope, however, that this compilation is comprehensive enough to be useful.

We wish to thank Drs. M. S. Vardya and T. N. Divine for their comments and for suggesting a number of ways of preparing a more useful bibliography.

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*See, for example, Schwarzschild, The Structure and Evolution of the Stars, 1958.
ABBREVIATIONS

A. J.
Ann. d'Phys.
Ap. J.
B. A. N.
Doklady
Geophysical J. R. A. S.
JETP
J. Phys. Soc. Japan
Mém. Soc. R. Sci. Liège
Mem. of the R. A. S.

Advances in Astronomy and Astrophysics,
Astronomical Journal
Annales d'Astrophysique
Annales de Physique
Annals of Physics
Annual Review of Astronomy and
Astrophysics
Annual Review of Nuclear Science
Astrophysical Journal
Astrophysical Journal Supplement
Australian Journal of Physics
Bulletin of the Astronomical Institutes
do the Netherlands
Bulletin of the American Physical Society
Canadian Journal of Physics
Soviet Physics Doklady
Geophysical Journal of the Royal
Astronomical Society
Soviet Physics JETP
Journal of the Physics Society of
Japan
Mémoires de la Société Royale de
Science à Liège
Memoirs of the Royal Astronomical Society
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<th>Abbreviation</th>
<th>Full Name</th>
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<td>M. N.</td>
<td>Monthly Notices of the Royal Astronomical Society</td>
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<td>M. N. ASSA</td>
<td>Monthly Notices of the Astronomical Society of South Africa</td>
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<td>Nuclear Phys.</td>
<td>Nuclear Physics</td>
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<tr>
<td>Observ.</td>
<td>The Observatory</td>
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<tr>
<td>Phys. Rev.</td>
<td>Physical Review</td>
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<tr>
<td>Prog. Theor. Phys.</td>
<td>Progress of Theoretical Physics</td>
</tr>
<tr>
<td>Rev. Mod. Phys.</td>
<td>Review of Modern Physics</td>
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<tr>
<td>Soviet Astr.</td>
<td>Soviet Astronomy</td>
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<tr>
<td>UCRL</td>
<td>University of California Lawrence Radiation Laboratory</td>
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<tr>
<td>Uspekhi</td>
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The Rotation of Main Sequence Stars.

Hydromagnetic Equilibria.

On the Shape of Magnetic Stars.

Hydromagnetic Equilibrium IV Axisymmetric Compressible Models.

A Magnetostatic Model for a Compressible Star.

On the Equilibrium and Oscillations of Magnetic Fluid Spheres.
IV. PROTO-STARS AND EVOLUTION PRIOR TO NUCLEAR BURNING


Contraction of a Protostar up to the Stage of Quasi-Static Equilibrium.

Pre-Main Sequence Stages of Stars.

Thermal and Dynamical Properties of a Protostar and its 
Contraction to the Stage of Quasi-Static Equilibrium.

Cameron, eds., 193. 
On Contracting Stars.

442. Herbig, G. H. (1962), Advances in Astronomy and Astrophysics, 
The Properties and Problems of T-Tauri Stars and Related Objects.


The Distribution of Pre-Main Sequence Stars in the H-R Diagram.

Stellar Evolution, I. The Approach to the Main Sequence. 

Stellar Formation Rates in Young Clusters.

Mass Loss from T-Tauri Stars.

Cameron, eds., 373. 
T-Tauri Mass Ejection.

M-R-L Relation and Contraction Time Scale for Convective 
Stars of Low Mass. 
(Abstract).

The Helmholtz-Kelvin Time Scale for Stars of Very Low Mass.

The Early Evolutionary Phases of Stars of Small Mass.
Models of Massive Stars in Homologous Gravitational Contraction.

Angular Momentum of Eclipsing Binaries and the Fission Theory of Their Origin.

KO Aquilae as an Example of Systems with Undersize Subgiant Secondaries in Pre-Main-Sequence Contraction.


A Theory of the Role of Magnetic Activity during Star Formation.

Role of Magnetic Activity during Stellar Formation.

Schematic Pre-Main-Sequence Evolution.


V. EQUILIBRIUM STAR MODELS AND EVOLUTION DURING NUCLEAR BURNING

A. Techniques of Model Construction


Time-Dependent Method for Computation of Radiation Diffusion and Hydrodynamics.


A New Method of Automatic Computation of Stellar Evolution.


Sternentwicklung I. Ein Programm Zur Lösung der Zeithängigen Aufbangleichungen.


An Application of Henyey's Approach to the Integration of the Equations of Stellar Structure.

Homologous Solutions of the Equations of Stellar Structure.

Some Remarks Concerning the Integral Theorems on the Internal Structure of Stars.
B. Stellar Models


Initial Composition: $X = .596$, $Z = .02$.
Mass: 2.0, 2.5, 3.5 and 5.0 $M_\odot$.
Construction Technique: Fitting.
Equation of State: Ideal gas; radiation pressure (Model I).
These models are compared to models in which radiation pressure is ignored (Model II).
Energy Transport: Completely convective core; radiative envelope (electron scattering or bound-free and free-free Kramers type opacity).
Energy Sources: pp chain, CNO cycle.
    Structure and Evolution of Medium Mass Stars IV. The Early
    Evolution of a Star of 2 Solar Masses.

    Initial Composition: \( X = .596, Y = .384, Z = .02, X_{CN} = .20 \ Z. \)
    Mass: \( 2(E) M_{\odot} \).
    Construction Technique: Fitting.
    Equation of State: Ideal gas, radiation pressure, electron
degeneracy.
    Energy Transport: Convective inner core, radiative outer
core, radiative envelope (Cox Tables),
and a surface convective region where
H I, He I and He II are partially ionized.
    Energy Sources: pp chain, CNO cycle, gravitational
potential energy changes.

    Structure and Evolution of Medium Mass Stars I. Main-Sequence
    Model of 2.5 Solar Masses.

    Initial Composition: \( X = .70, Y = .28, Z = .02, X_{CN} = .19 \ Z. \)
    Mass: \( 2.5 M_{\odot} \).
    Construction Technique: Fitting.
    Equation of State: Ideal Gas.
    Energy Transport: Convective core; radiative envelope-Kramers
type opacity plus electron scattering
(as in Iben, Ehrman 1962).
    Energy Sources: pp chain, CN cycle; (interpolative fit to
Wrubel 1958) sources in the outer radiative
zone are included.

    A Model for a Homogeneous Star of Moderate Mass.

    Initial Composition: \( X = .73, Y = .25, Z = .02. \)
    Mass: \( 1.48 M_{\odot} \).
    Construction Technique: Fitting.
    Equation of State: Ideal gas throughout.
    Energy Transport: Polytropic core (\( n = 1.5 \)); radiative zone
(opacities are an interpolative fit to
Keller-Meyerott 1955); convective envelope
(an E solution).
Energy Sources: pp, CN (interpolative fit to B^2FH 1957 and Fowler 1958) the ratio of the energy produced by pp to that produced by CN is the free parameter in the model. A value of .327472 gives the best fit to the empirical Main-Sequence.


Initial Composition: 
\[ X = .76, Z = .0025, X = .85, Z = .0025 \]
\[ X = .93, Z = .0025, X = .99, Z = .0025 \]
Z is all CN.

Masses: 1(E), 2(E), 4(E), 8(E), 16(E), 32(E), 64(E), 128(E) M_☉ for each composition.

Construction Technique: Fitting.

Equation of State: Ideal gas, radiation pressure.

Energy Transport: Interpolative fit to Keller-Meyerott opacities in radiative zones.

Energy Sources: pp, CN interpolation formulae, early evolutionary stages are calculated for \( X = .85 \) for each mass.

(See Haselgrove and Hoyle, M. N. 1956).


Initial Composition: 
I. \( H = .68, He^4 = .29, C^{12} = .0042, \]
\[ C^{13} = 5.4(-5)*, N = 1.45(-3), O = 1.31(-2). \]
II. \( H = .68, He^4 = .29, C^{12} = .00016, \]
\[ C^{13} = 5.4(-5), N = 5.49(-3), O = 1.31(-2). \]
III. \( H = .68, He^4 = .29, C^{12} = .00016, \]
\[ C^{13} = 5.4(-5), N = 1.359(-2), O = 5(-3). \]
IV. \( H = .68, He^4 = .29, C^{12} = .0028, \]
\[ C^{13} = 3.6(-5), N = 9.67(-4), O = 8.74(-3). \]

Mass: 2.3 M_☉.

Construction Technique: Henyey.

Equation of State: Ideal gas, radiation pressure, incomplete ionization, degeneracy.

Energy Transport: Opacity: interpolative fit to Keller Meyerott Table updated to Cox and Eilers values. Includes electron conduction.

*Numbers in parentheses are the powers of 10 by which the corresponding entries are to be multiplied.

Studies in Stellar Evolution II. Lithium Depletion During the Pre-Main Sequence Contraction.

Initial Composition: $X = .66, Z = .0264$, $X = .38, Z = .015$

Mass: $1.0(E), 0.8(E), 1.2(E) M_{\odot}$, $0.5(E), 0.59(E), 0.68 (E) M_{\odot}$.

Construction Technique: Henyey.

Equation of State: Ideal gas, radiation pressure, incomplete ionization, degeneracy.

Energy Transport: Fully convective pre-main sequence contraction, mixing length theory is used in outer convection zone. The radiative opacity used upon the onset of the radiative core is from BFGH (1965).

Energy Sources: pp chain, CNO bi-cycle cf. BFGH (1965), Li$^7$ (p,α)He$^4$, Li$^7$(p,α)He$^3$ burning, gravitational energy release.

Modelés des étoiles composés d'hydrogène.

Initial Composition: $X = 1$.

Mass: $20 \leq M/M_{\odot} \leq 6650$.

Energy Transport: Convective core; outer radiative zone, electron scattering opacity.

Contribution à l'étude des étoiles formées initialement d'hydrogène pur.

Initial Composition: $X = 1.0$.

Masses: $174(E), 306(E), 611(E), 1515(E), 6645(E) M_{\odot}$.

Construction Technique: Fitting.

Equation of State: Ideal gas, radiation pressure.

Energy Transport: Convective core, radiative envelope (electron scattering opacity).

Energy Sources: pp chain, 3α reaction, CNO chain.

Initial Composition: \( X = 0, Y = 0.98, Z = 0.02 \).
Mass: \( 2.9, 5.5, 9.0, 14.6, 24.3, 43.0, 85, 214 \) \( \text{M}_\odot \).
Construction Technique: Fitting.
Equation of State: Ideal gas, radiation pressure.
Energy Transport: Electron scattering opacity in envelope, convective core.
Energy Sources: 3\( \alpha \) alone—interpolation formula.


Initial Composition: \( X = 0, Y = 1.0 \).
Mass: \( 0.5, 1, 2, 3, 4, 5, 6, 7, 8, 9 \) \( \text{M}_\odot \).
Construction Technique: Fitting.
Equation of State: Ideal gas.
Energy Transport: Convection in core \(( n = 1.5 )\), radiative envelope with electron scattering opacity.
Energy Sources: Entirely 3\( \alpha \) helium burning (Salpeter 1957).


Hydrogen rich envelopes are fitted to the previous models (Cox and Guili 1961). The main result is a greatly expanded radius and reduced effective temperature.


Initial Composition: \( X = 0, Y = 1.0 \).
Mass: \( 0.31, 0.35, 0.40, 0.50, 0.75, 1.0, 1.25, 1.50, 2.0, 4.0, 8.0 \text{ \text{M}_\odot} \) initial models; \( 0.31(\text{E}), 0.50(\text{E}), 1.0(\text{E}), 2.0(\text{E}) \text{ \text{M}_\odot} \) inhomogeneous evolving models.
Construction Technique: Fitting, radiative zero boundary conditions.

Equation of State: Non-relativistic, partially degenerate electrons, ideal ions.

Energy Transport: Convective core; electron conduction and electron scattering opacity in the radiative envelope.

Energy Sources: 3α reaction in homogeneous models; Cl2(α,γ)O16 added in inhomogeneous models (Reeves, 1964).


Initial Composition: \( X = 0, Y = 1.0. \)

Mass:
\[
0.4832, 0.9844, 2.292, 3.986(E), 6.588, 14.80(E), 32.10, 78.21(E), 387.7(E), 4705(E), \infty, M_\odot \text{ for homogeneous models.}
\]

Construction Technique: Fitting.

Equation of State: Ideal gas, radiation pressure. (Degenerate corrections made for small M).

Energy Transport: Electron scattering opacity.

Energy Sources
He burning, 3α reaction for initial homogeneous models (Salpeter 1957), Cl2(α,γ)O16, O16(α,γ)Ne20, Ne20(α,γ)Mg24, Mg24(α,γ)Si28 included for evolving inhomogeneous models. (Reeves 1964).

Models for Carbon-Burning Stars.

Initial Composition: \( X = Y = 0, Z = 1, \) Carbon burning models are consistent with \( X_c \sim 0.02 \text{ to } 0.03. \)

Masses:
\[
0.499, 0.454, 0.718, 0.963, 1.538, 5.22, 9.97, 26.73 (T_c = 3 \times 10^{8}\text{K, without neutrino}), 0.819, 0.796, 0.972, 1.623 (\text{with neutrinos}), 1.645, 5.58 (T_c = 5 \times 10^{8}\text{K, without neutrinos}), 19.4, 27.2 (\text{with neutrinos}), \text{ (for the gravitational contracting models).}
\]

Construction Technique: Fitting.

Equation of State: See Deinzer and Salpeter (above).

Energy Transport: See Deinzer and Salpeter (above), opacity includes relativistic correction to electron scattering.
Energy Sources: Carbon Burning (Reeves 1963) or gravitational potential energy release. Neutrino sink is included and these models are compared with identical models without neutrino losses.

Interior Models for Subdwarf Stars.
(Abstract in A. J., 64, 327).

Initial Composition: X = .75, Z = .001, X = .75, Z = .01,
X = .999, Z = .001, X = .99, Z = .01.
Mass: .6, .8, 1.0 M\(_{\odot}\).
Construction Technique: Fitting.
Equation of State: Perfect gas.
Energy Transport: Convective envelope; radiative core, opacity is an interpolative fit to Keller Meyerott.
Energy Sources: pp chain.

The Structure of Population II Stars.

Initial Composition: X = .999, Z = .001; X = .99, Z = .01;
X = .75, Z = .005; X = .75, Z = .001;
X = .75, Z = .01.
Mass: .6, .8, 1.0 M\(_{\odot}\).
Construction Technique: Fitting.
Equation of State: Perfect gas.
Energy Transport: Inner radiative zone-interpolative fit to Keller Meyerott opacities. Outer convective zone - adiabatic convection in inner part, mixing length theory in outer parts.
Energy Sources: pp chain \(\epsilon = \epsilon_0 \rho T^4\) interpolation formula.

Models for Lower Main Sequence Population II Stars.

For particulars see the paper above (Demarque 1960). These models just show the effect of changing the mixing length to 2x the pressure scale height in the convective zone.
Models for Red Giant Stars I.

Initial Composition: $X = .999, Y = 0, Z = .001$ (Both masses);
$X = .99, Y = 0, Z = .01$ (1.2 $M_\odot$);
$X = 1.0, Y = 0, Z = .0$ (1.2 $M_\odot$);
$X = .749, Y = .25, Z = .001$ (1.2 $M_\odot$).

Mass: $1.0(E), 1.2(E)M_\odot$.

Construction Technique: Fitting.

Equation of State: Partially degenerate electrons, ideal nuclei in core, ideal gas outside.

Energy Transport: Isothermal core; radiative zone-Keller Meyerott opacities with bound-bound neglected; outer convective zone - mixing length theory with $\xi \equiv$ pressure scale height.

Energy Sources: CN cycle, pp cycle $^3$He($^3$He,2$^3$He)$^4$He; $^3$He($\alpha$,y)$^4$Be($^7$Li,$^7$Be)+$^7$Li($p$,y)$^8$He - interpolation formula.

The Age of Galactic Cluster NGC 188.

Initial Composition: $X = .57, .67, .77, Z = .03$.

Masses: $.8(E), .9(E), 1.0(E), 1.1, 1.2, 1.3, 1.4 M_\odot$ (only the X = .67 models are evolutionary).

Construction Technique: Modified Henyey (Demarque and Larson 1964).

Energy Transport: Keller Meyerott fit in radiative zones, mixing length theory in convective zones, $\xi/H = 1.6, 2$.

Energy Sources: pp chain (three branches), CN chain -- Reeves 1964.

A series of Solar Models.

Initial Composition: $Z = .02$ for $X = .78, .76, .74, .72, .70$;
$Z = .025$ for $X = .74, .72, .70, .68, .66$;
$Z = .030$ for $X = .72, .70, .68, .66, .64$;
$Z = .035$ for $X = .70, .68, .66, .64$;
$Z = .040$ for $X = .68, .66, .64$.

Mass: 1 $M_\odot$.

Construction Technique: Modified Henyey.
Equation of State: Ideal gas, degenerate electrons.

Energy Transport: Fit to Keller-Meyerott opacities in radiative zone; mixing length theory in outer convection zone.

Energy Sources: Reeves (1964).

Structure and Evolution of Model Helium Stars.

Initial Composition: X = 0.0, Y = 0.999, Z = 0.001.

Mass: 0.4, 0.5(E), 0.620, 0.765, 0.8, 1.0(E), 1.25, 1.5, 2.0, 3.0, 4.0, 6.0(E), 8.0, 10.0, 12.5, 14.8, 20.0, 32.1, 40.0, 60.0 M_{\odot}.

Construction Technique: Henryey.

Equation of State: Radiation pressure; ideal ions; ionization of He; semi-relativistic, partially degenerate electrons.


Energy Sources: Gravitational Contraction; 3α, C^{12}(α,γ)O^{16}, O^{16}(α,γ)Ne^{20} Reactions.

Models of Massive Pure Hydrogen Stars.

Initial Composition: X = 1.0.

Mass: 1, 2, 5, 10, 20, 50, 100, 200, 300, 500, 750, 1000, 2000 M_{\odot}.

Construction Technique: Fitting.

Equation of State: Ideal gas, radiation pressure.

Energy Transport: Convective core (n = 1.5); Kramers opacity, interpolation for $\kappa_0$ in radiative zones.

Energy Sources: pp chain $(\text{He}^3(\text{He}^3,2p)\text{He}^4)$ interpolation formula B^2FH(1957) corrected by Fowler (1959).
A Study in Solar Evolution.

Initial Composition:
\[ X = 0.739, \quad Y = 0.240, \quad Z = 0.021, \quad X_{12} = 4.618 \times 10^{-3}, \quad X_{14} = 0.97 \times 10^{-3}, \quad X_{016} = 1.0715 \times 10^{-2}. \]

Mass:
1.0 \( M_\odot \) (E).

Construction Technique:
Henyey Method.

Equation of State:
Radiative Zones; Los Alamos opacity tables.
Convective zones; mixing length theory.
\((\xi = 2H)\).

Energy Transport:
Gravitational Energy; \( H^2 \), \( He^3 \) burning, \( \alpha \) pp chains, CNO bi-cycle (interpolation formulae).

On the Nature of the Horizontal Branch, I. (Models for stars that have passed through the helium flash).

Initial Composition:
\[ X = 0.9, \quad Z_{\text{CNO}} = 0.5, \quad Z = 10^{-5}, 10^{-4}, 10^{-3}, 10^{-2}. \]

Mass:
1.25 \( M_\odot \) (\( M_{\text{core}} = 0.4, 0.5 \ M_\odot \)).

Construction Technique:
Fitting.

Equation of State:
Ideal gas, radiation pressure.

Energy Transport:
Electron scattering, bound-free, free-free fit to Keller Meyerott. Central convection.

Energy Sources:
3\( \alpha \) reaction, CNO bi-cycle, pp reaction.

The Evolution of Population II Stars.

Initial Composition:
\[ X = 0.65, \quad Z_{\text{CNO}} = Z/2 = 10^{-3}, 10^{-4}, 10^{-5}, 10^{-4}, 10^{-5}. \]

Masses:
0.65, 0.70, 0.75, 0.70, 0.75, 1.25(E), 1.0, 1.25(E), 1.0, 1.25(E).

Rest as in Iben (1965) except that electron degeneracy is included.

Initial Composition: \( X = 0.0, Y = 0.98, Z = 0.02 \).
Mass: \( 2.9 (E), 14.6(E) M_\odot \).
Construction Technique: Fitting.
Equation of State: Ideal gas, radiation pressure.
Energy Transport: Convective core; radiative envelope with electron scattering opacity.
Energy Sources: \( 3\alpha, {\alpha + n}\gamma, {\alpha + p}\gamma, {\alpha + p}\gamma \) reactions.

Evolution is carried to helium exhaustion in the core. Abundances of the elements are followed and compared.


Initial Composition: \( \text{He}^4, \text{C}^{12}, \text{Mg}^{24}, \text{Si}^{28}, \text{S}^{32}, \text{or} \text{F}^{56} \), and one with equilibrium composition of these.
Masses:
\( \begin{align*}
\text{He}^4: & \ 0.154, 0.213, 0.305, 0.399, 0.499, 0.609, 0.734, 0.885; \\
\text{C}^{12}: & \ 0.147, 0.488, 0.597, 0.722, 0.872, 1.07, 1.206, 1.318, 1.366, 1.381, 1.396, 1.349, 1.174; \\
\text{Mg}^{24}: & \ 0.139, 0.196, 0.286, 0.378, 0.476, 0.584, 0.708, 0.857, 1.053, 1.19, 1.3, 1.348, 1.363, 1.282, 1.205; \\
\text{Si}^{28}: & \ 1.319, 1.343, 1.175; \\
\text{Si}^{32}: & \ 1.011, 1.169, 1.064, 1.067, 1.047; \\
\text{Fe}^{56}: & \ 0.007, 0.015, 0.015, 0.024, 0.046, 0.103, 0.149, 0.222, 0.298, 0.380, 0.471, 0.576, 0.703, 0.872, 0.991, 1.088, 1.112, 1.093, 1.028, 1.014, 0.990.
\end{align*} \)

Construction Technique: Numerical integration of the mechanical equilibrium equations.
Equation of State: Salpeter (1961) for matter at high densities.
Energy Transport: None, Zero temperature stars.
Energy Sources: None, Zero temperature stars.
Red Giants of Population II. III.

Initial Composition:  
\[ X = 0.9, \ Y = 0.099, \ Z = 0.001 \ (M = 1.0, 1.3); \]
\[ X = 0.9, \ Y = 0.09, \ Z = 0.01 \ (M = 1.3). \]

Mass:  
\[ 1.0(\text{E}), \ 1.3(\text{E}) \ M_{\odot}. \]

Construction Technique:  
Henyey method.

Equation of State:  
Isothermal degenerate core; convective envelope--interpolation formula at boundary.

Energy Sources:  
See earlier paper (1962) for other assumptions--difference here is the Henyey method.

Giant Stars of Type II (see Haselgrove and Hoyle 1956, M. N.).

Initial Composition:  
\[ X = 0.9309, \ Y = 0.0666, \ Z = 0.0025. \]

Mass:  
\[ 1.27 (\text{E}) \ M_{\odot}. \]

Construction Technique:  
Fitting.

Equation of State:  
Ideal gas, radiation pressure.

Energy Transport:  
Conduction included, interpolated radiative opacity.

Energy Sources:  
pp, CN cycles — interpolation formulae.

Main Sequence Stars.

Initial Composition:  
I  \[ X = 0.75, \ Y = 0.24, \ Z = 0.01 \]
II  \[ X = 0.99, \ Y = 0.009, \ Z = 0.001 \]
III  \[ X = 0.75, \ Y = 0.249, \ Z = 0.001. \]

Masses:
I  \[ 1.01, 1.09, 1.19, 1.29, 1.40, 1.46, 1.52, \]
\[ 1.97, 2.89, 3.44, 3.90, 5.97, 8.95, 13.4, \]
\[ 20.1, 30.2, 37.0, 55.5, 83.3, 125. \ M_{\odot}. \]
II  \[ 1.06, 1.20, 1.25, 1.35, 1.47, 1.60, 1.74, \]
\[ 2.07, 2.46, 2.68, 2.91, 3.47, 4.00 \ M_{\odot}. \]
III  \[ .987, 1.02, 1.17, 1.34, 1.43, 1.52, 1.61, \]
\[ 1.94, 2.43, 3.05 \ M_{\odot}. \]

Construction Technique:  
Fitting.

Equation of State:  
Ideal gas, radiation pressure.
Energy Transport: Radiative zones--fit to Keller-Meyerott tables (10%), conduction was included and a special solution for the outermost zones is described.

Energy Sources: pp chain (three branches), CN cycle--interpolation formulae.


Initial Composition: \( X = 0.90, Y = 0.08, Z = 0.02, X_{CN} = Z/3 \).
Mass: \( 15.6 \, M_\odot \) (E).
Construction Technique: Fitting.
Equation of State: Ideal gas, radiation pressure.
Energy Transport: Electron scattering opacity in radiative zones, convective core.
Energy Sources: \( 3\alpha \) process in core
CN cycle in outer shell \( \text{interpolation formulae} \).


Initial Composition: \( X = 0.61, Y = 0.37, Z = 0.02, X_{CNO} = 0.008 \)
Model begins with \( X = 0 \) in core.
Mass: \( 4 \, M_\odot \) (E).
Construction Technique: Fitting.
Equation of State: Ideal gas.
Energy Transport: Radiative zones--outer, B-F Kramers opacity; inner, electron scattering.
Energy Sources: CNO cycle \( \text{interpolation formulae} \) (B'FH 1957)
\( 3\alpha \) reaction (Salpeter 1957).
   Evolution of the Stars.

   Includes many results for the 15.6 and 4.0 M\(_\odot\) stellar models described in the papers above. This paper also includes work on a 0.7 M\(_\odot\) model, on the pre-main sequence contraction, and on the white dwarf and pre-white dwarf stages of evolution.

   The Evolution of Massive Stars III. Hydrogen Exhaustion through the Onset of Carbon Burning.
   (Notes in A. J., 65, 490; 67, 577).

   Initial Composition: \(X = 0.90, Y = 0.08, Z = 0.02, X_{\text{CNO}} = Z/3,\)
   \((15.6 \, M_\odot \text{ evolution is carried to onset of Cl}\_2 \text{ or Ne20 burning.}) \, X = 0.61, Y = 0.37, Z = 0.02, (10.1 \, M_\odot)\)
   Mass: \(15.6(\text{E}), 10.1(\text{E}) \, M_\odot.\)
   Construction Technique: Fitting.
   Equation of State: Perfect gas, radiation pressure.
   Energy Transport: Radiative opacity is electron scattering alone.
   Energy Sources: CNO, pp, 3\(\alpha\) interpolation formulae (Fowler 1960, Salpeter 1957); gravitational contraction included.

   Evolution with Neutrino Loss of a Massive Star until the Onset of Carbon Burning.
   (Abstract).


   (Continuation of Prog. of Theor. Phys. Suppl #22 by same authors).

   Evolution of Main Sequence Stars.

   Initial Composition: \(X = 0.68, Y = 0.31, Z = 0.01, \text{ evolution carried till } X \sim 0 \text{ in the core.}\)
   Mass: \(1.5(\text{E}), 2(\text{E}), 3.5(\text{E}), 6(\text{E}), 11(\text{E}), 20(\text{E}), 30(\text{E}).\)
Construction Technique: Henyey.

Equation of State: Ideal gas, radiation pressure, degeneracy (by interpolation formula).

Energy Transport: Convective cores; interpolative fit to Keller-Meyerott, (40%) opacities in radiative zones.

Energy Sources: pp chain completed by He$^3$(He$^3$,2p)He$^4$—interpolation to fit Salpeter 1950; CN chain—interpolation to fit Bösemann-Crespin 1954 values.

Stellar Models with Isothermal Cores and Intermediate Convective Zones.

Initial Composition: $\mu_i/\mu_e = 1.0, 1.5788, 2.5, 2.6667$.

Mass: $1.82 M_\odot$ (E).

Construction Technique: Fitting.

Equation of State: Ideal Gas.

Energy Transport: $p = E^{2.5}$ in intermediate convective zone. Kramers opacity in outer radiative zones.

Energy Sources: Shell source; interpolation formula.

Sternentwicklung II. Die Wasserstoff-brennende Phase eines Sternes von 7.0 Sonnenmassen.

Initial Composition: $X = .602, Y = .354, Z = .044$.

Mass: $7 M_\odot$ (E).

Construction Technique: Henyey (see Hofmeister, Kippenhahn, Weigert 1964).

Equation of State: Ideal gas.

Energy Transfer: Outer Convective Zone: mixing length theory, $\ell = 1.5$ the pressure scale height. Outer radiative layers: opacities from tables by Baker (line absorption ignored). Inner Radiative layers: Opacity table derived from Keller-Meyerott tables (line absorption ignored), electron scattering, electron conduction included.

Energy Sources: CNO bi-cycle initially, pp cycles (in shell), 3a process (in core) are ignited in later stages—interpolation formulae used.
Sternentwicklung III. Die Helium-brennende Phase und die Cepheid-
enstadien eines Sterns von 7.0 Sonnenmassen.

See paper II above. This is a continuation through the Helium Burning Phase.

The Ages of Type I and Type II Subgiants.

Initial Composition:  
X = .99, Y = .009, Z = .001  1.35 M₀;  
X = .75, Y = .249, Z = .001  1.16 M₀;  
X = .75, Y = .24, Z = .01  1.09 M₀;

Mass:  
1.09(E), 1.16(E), 1.35(E) M₀.

See Haselgrove and Hoyle (1959) for details.

On the Main-Sequence Band and the Hertzsprung Gap.

Initial Composition:  
X = .75, Y = .23, Z = .02, evolution to the point where X₞ < 0 is considered.

Mass:  
1.52(E), 3.89(E), 8.94(E), 30.1(E) M₀.

See Haselgrove and Hoyle (1959) for the rest.

The Internal Structure of Middle Main Sequence Stars.

Initial Composition:  
I. X = .8, Z = .02; II. X = .7, Z = .02;  
III. X = .6, Z = .02; IV. X = .75, Z = .015;  
V. X = .8, Z = .01; VI. X = .7, Z = .01;  
XCN = .18 Z.

Mass:  
Composition  
I. 1.25, 1.581, 1.794, 2.10, 2.63 M₀;  
II. .886, 1.05, 1.256, 1.354, 1.506,  
1.866, 2.280, 2.864 M₀;  
III. .0865, 1.21, 1.303, 1.563, 1.86, 2.26  
M₀;  
IV. 1.112, 1.44, 1.596, 1.87, 2.135, 3.078  
M₀;  
V. 1.175, 1.420, 1.706, 2.02, 2.32,  
2.85 M₀;  
VI. 2.172, 1.811, 1.470, 1.07 M₀.

Construction Technique:  
Fitting.

Equation of State:  
Ideal Gas.
Energy Transport: Radiative opacities are an interpolative fit to Keller-Meyerott values.

Energy Sources: pp chains, and CN cycle-interpolation formula.

Stellar Evolution II. The Evolution of a 3 $M_\odot$ Star from the Main Sequence through Core Helium Burning.

Initial Composition: $X = 0.708$, $Z = 0.02$.
Mass: $3 (E) M_\odot$.
Construction Technique: Henyey.
Equation of State: Ideal gas; radiation pressure; electron degeneracy except in surface regions.
Energy Transport: Convective core; free-free, bound-free absorption, and electron scattering radiative opacity (cf. Iben and Ehrman 1962 (use in interior) and Iben 1963 (in regions of partial H-ionization)). Electron conduction is included.
Energy Sources: pp chain, CN cycle, gravitational contraction, Cl$^2$ depletion.

Stellar Evolution III. The Evolution of a 5 $M_\odot$ Star from the Main Sequence through Core Helium Burning.

(As above (Iben, 1965) except the mass is 5 $M_\odot$ (E) and variations in the Cl$^2 (\alpha,\gamma)$O$^{16}$ cross section are considered).

Stellar Evolution IV. The Evolution of a 9 $M_\odot$ Star from the Main Sequence through Core Helium Burning.

(As above (Iben, 1965) except the mass is 9 $M_\odot$).

Stellar Evolution V. The Evolution of a 15 $M_\odot$ Star from the Main Sequence through Core Helium Burning.

(As above (Iben 1965) except the mass is 15 $M_\odot$. The evolution is compared to that of the less massive stars above and the 15.6 $M_\odot$ model of Hayashi et. al., (1962)).
Evolutionary Model Sequence of a Star of Ten Solar Masses.

The Internal Structure of M Dwarf Stars.

Initial Composition:
- \( X = 0.664, Z = 0.008 \)
- \( X = 0.500, Z = 0.029 \)
- \( X = 0.56, Z = 0.01 \)
- \( X = 0.50, Z = 0.03 \)
- \( X = 0.48, Z = 0.009 \)

Mass: \( 0.162, 0.209, 0.269 \, M_\odot \).

Construction Technique: Fitting.

Equation of State: Ideal gas, degenerate electrons.

Energy Transport: Convective envelope \((n = 1.5)\); radiative core-modified Kramer's opacity (Morse 1940).

Energy Sources: pp cycle, interpolation (B"FH 1957).

Sternmodelle I. Die Entwicklung der Sterne der Population II.

Initial Composition: \( X = 0.9, Y = 0.1, X_{\text{CN}} = 0.0005 \).

Mass: \( 1.2 \, M_\odot \) (E).

Construction Technique: Fitting.

Equation of State: Ideal gas, electron degeneracy, radiation pressure.

Energy Transport: Convective (Mixing length theory) plus radiation in outer layers; the radiative opacity includes the effects of the negative \( \mathrm{H} \) ion, neutral hydrogen, \( \mathrm{H} \) ionization, \( \mathrm{f} \) and higher ionization and electron scattering by various interpolation formulae.

Energy Sources: pp, CN chain, interpolation formulae (Hoyle-Schwarzschild 1955).

Sternentwicklung IV. Zentrales Wasserstoff-und Heliumbrennen bei einem Stern von 5 Sonnenmassen.

Initial Composition: \( X = 0.602, Y = 0.354, Z = 0.044 \).

Mass: \( 5 \, M_\odot \) (E).
See papers II, III, (Hofmeister, Kippenhahn, Weigert, 1964). Follow the evolution through helium exhaustion in the core. The results are compared with those for the $7 M_\odot$ Star of papers II and III.


Initial Composition: 
\begin{align*}
X &= .70 \\
Z &= .05 \\
X_{\text{CNO}} &= Z/7 \\
X_{\text{CNO}} &= Z/7.
\end{align*}

Mases: 
\begin{align*}
20, 30 M_\odot (E) \\
15.6 M_\odot (E).
\end{align*}

Construction Technique: Henyey.

Equation of State: Ideal gas, radiation pressure.

Energy Transport: Free-free and bound-free transitions, electron scattering in radiative opacity. Convective core, intermediate radiative zone as core contracts.

Energy Sources: pp chain, CN cycle, gravitational energy.


Initial Composition: 
\begin{align*}
\text{I.} & \quad X = .90, Y = .09, Z = .01, \\
\text{II.} & \quad X = .62, Y = .35, Z = .03.
\end{align*}

Mass: 
\begin{align*}
.04, .05, .06, .07, .08, .09.
\end{align*}

Construction Technique: Integrate equations for a polytrope.

Equation of State: Non-relativistic, partially to completely degenerate electrons (see Kumar 1962).

Energy Transport: Completely Convective ($n = 1.5$) electron conduction ignored.

Energy Sources: Gravitational Contraction; $H^2$, $Li^6$, $Li^7$, $Be^9$, $B^{10}$, $B^{11}$ burning during contraction.


Initial Composition: 
\begin{align*}
X &= .899, Y = .100, Z = .001, \\
X &= .891, Y = .099, Z = .01.
\end{align*}

Mass: 
\begin{align*}
1.2 M_\odot (E).
\end{align*}
Construction Technique: Fitting.

The Structure of M Dwarf Stars, II.

Initial Composition: $X = .75, Y = .23, Z = .02$.
Mass: $0.0912, .1, .11, .126, .158, .251, .398, .631, 1.00$.
Construction Technique: Completely convective models--fitting unnecessary.
Equation of State: Partially degenerate electrons, ideal ions.
Energy Transport: Adiabatic convection in partially degenerate material.
Energy Sources: $\text{pp chain} - \varepsilon = \varepsilon_0 \rho T^\nu, \quad 4 \leq \nu \leq 6.5$ fit to Salpeter 1952.

The Structure of the Sun.

Initial Composition: $X = .995, Y = .003, Z = .002$.
Mass: $1.0 M_\odot$.
Construction Technique: Fitting.
Equation of State: Ideal gas.
Energy Transport: Convection in core, Kramers plus electron scattering opacity in radiative zone -- fit to Morse 1940.
Energy Sources: $\text{pp chain in outer layers, CN chain in core--interpolation formulae}$.

Initial Model of a Massive Star.

Initial Composition: $X = .75, Y = .22, Z = .03$.
Mass: $28 M_\odot$.
Construction Technique: Fitting.
Equation of State: Ideal gas, radiation pressure.
Energy Transport: Convective core, radiative envelope-Kramers's opacity fit to Keller-Meyerott opacities plus electron scattering.
Energy Sources: pp chain, CN chain; interpolation formulae from Haselgrove and Hoyle.

On Stellar Models with Double Energy Sources.

Initial Composition: \( X = 0.90, Y = 0.10, X_N = 0.0005 \) initial and envelope; begins with pure helium core.

Mass: \( 1.2 \, M_\odot \).

Construction Technique: Fitting.

Equation of State: Ideal gas.

Energy Transfer: \( ff \) opacity in outer envelope; electron scattering in inner envelope—no contribution from anything other than \( H, \ He \). Also has a pure \( He \) convective core \((n = 1.5)\) and an intermediate \( He \) radiative zone.

Energy Sources: \( 3\alpha \) in \( He^{4} \) core, CN cycle in thin shell; interpolation formulae (Hayakawa).

Evolution of Population II Stars in Helium-Burning Phase.

See above (Nishida 1960) for details.

Model for a Helium Star of One Solar Mass.

Initial Composition: \( X = 0, Y = 0.999, Z = 0.001 \).

Mass: \( 1 \, M_\odot \).

Construction Technique: Fitting.

Equation of State: Ideal gas.

Energy Transport: Convective core; outer radiative zone, opacity on interpolation to fit Keller-Meyerott tables.

Energy Sources: \( 3\alpha \) \( He \) burning in core above, \( \rho^{2+30} \) interpolation formula.
   Evolution of Helium Burning Stars of .8 Solar Masses.

   Initial Composition:
   I. $Y = 1$; II. $Y = 1$ for $0 \leq M_r / M \leq .85$, $X = .9$, $Y = .099$, $Z = .001$ in envelope.
   III. $Y = 1$ for $0 \leq M_r / M \leq .85$, $X = .9$, $Y = .099$, $Z = .001$ in envelope.

   Mass: .8 $M_\odot$ (E).

   Construction Technique: Fitting.

   Equation of State: Ideal gas, degenerate electrons.

   Energy Transport: Convective core ($n = 1.5$); electron scattering opacity alone in the radiative envelope.

   Energy Sources: 3a reaction, $\frac{3}{2}^2 T^{30}$ interpolation formula.

   Structure and Evolution of Medium-Mass Stars II. The Extent of the Convective core in Middle Main Sequence Stars.

   Initial Composition:
   I. $X = .8$, $Z = .02$, $X_{CN} = .19 Z$
   II. $X = .8$, $Z = .01$, $X_{CN} = .19 Z$
   III. $X = .7$, $Z = .02$, $X_{CN} = .19 Z$
   IV. $X = .7$, $Z = .01$, $X_{CN} = .19 Z$
   V. $X = .6$, $Z = .02$, $X_{CN} = .19 Z$.

   Mass: $0.9 M_\odot \leq M \leq 2.0 M_\odot$.

   Construction Technique: Fitting.

   Equation of State: Ideal gas.

   Energy Transport: Convective core; radiative envelope.

   Energy Sources: pp chain, CN cycle - includes energy generation in the envelope.


   A Revised Solar Model with a Solar Neutrino Spectrum.

   Initial Composition: $X = .68$, $Y = .276$, $Z = .044$, $X_{CN} = .0091$.

   Mass: 1 $M_\odot$.

   Construction Technique: Henyey.

   Equation of State: Ideal Gas.

   Energy Transport: Interpolated opacity - fit to Los Alamos opacities (Cox and Stewart) in radiative zones. Convective envelope has $\log K = -2.25$ chosen to give correct radius.

   Energy Sources: H burning - from Reeves 1964.
Variation of the Gravitational Constant and the Evolution of the Sun.

Initial Composition: \(0.68 \leq X \leq 0.81\) Variable with variation in \(G\) to give correct present sun. \(Z = 0.04\).

Mass: \(1\ M_\odot (E)\).

Construction Technique: Henyey method.

Equation of State: Ideal gas throughout.

Energy Transport: Interpolation formula for opacity in envelope; convective core with \(K\) chosen to give fit to radius.

Energy Sources: pp, CN chains - interpolation formulae.

The Transition from Hydrogen-Burning to Helium-Burning in a Star of 5 Solar Masses.

Initial Composition: \(X = 0.74, Y = 0.24, Z = 0.02, X_{CN} = Z/7\).
Evolution carried until \(X \sim 0\) in core and He burning begins.

Mass: \(5\ M_\odot (E)\).

Construction Technique: Fitting.

Equation of State: Ideal gas.

Energy Transport: convective core (usual tabulated solution); electron scattering plus modified Kramer's opacity in radiative envelope.

Energy Sources: Carbon cycle, \(\rho X_{CN} T^{16}\) interpolation formula; gravitational energy release in evolution of core.

Calculations of Main Sequence Stellar Models.

Initial Composition: \(X = 0.70, Z = 0.03, X_{CNO} = 0.6\ Z\).

Mass: \(6(E), 10(E), 15(E) M_\odot\).

Construction Technique: Fitting.

Equation of State: Ideal gas, radiation pressure.

Energy Transport: radiative opacity tables include bound-free, free-free, and electron scattering contributions.

Energy Sources: pp chain, CNO cycle (interpolation to Reeves 1964); gravitational energy release.
A New Solar Model.
(Abstract).


Initial Composition: \( Y = 1.0 \).
Mass: \( .4, .5, .75 \, M_\odot \).
Construction Technique: Henyey.
Equation of State: Ideal gas, electron degeneracy.
Energy Sources: \( 3\alpha \) reaction (Cox and Salpeter, 1964).

Evolution of Massive Stars I.

Initial Composition: \( X = .90, Y = .08, Z = .02, X_{\text{CN}} = Z/3 \).
Mass: \( 15.6 \, M_\odot \, (E) \).
Construction Technique: Fitting.
Equation of State: Ideal gas, radiation pressure.
Energy Transport: Electron scattering alone in radiative zones, convective core.
Energy Sources: \( \text{CN cycle, } \rho T^{16} \) interpolation formula.

Internal Structure and Evolution of Very Massive Stars.

Initial Composition: \( X = .9, Y = .08, Z = .02 \).
Mass: \( 46.8 \, M_\odot \, (E) \).
Construction Technique: Fitting.
Equation of State: Ideal gas, radiation pressure.
Energy Transport: Electron scattering opacity in envelope, semi-convective intermediate zone and fully convective core.
Energy Sources: \( \text{CN cycle, } \epsilon \rho T^{16} \) interpolation formula to fit (B2FH 1957).
Internal Structure of Very Massive Stars.
See previous paper (Sakashita and Hayashi (1959)).

Early Evolution at Mass Ten.

Initial Composition: \( X = .70, Y = .27, Z = .03 \).
Mass: \( 10 M_\odot \) (E).
Construction Technique: Fitting.
Equation of State: Ideal gas, radiation pressure.
Energy Transfer: Electron scattering plus Kramers opacity in radiative zones.
Energy Sources:

Evolution of Very Massive Stars.

Initial Composition: \( X = .75, Y = .22, Z = .03 \).
Mass: \( 28.2(E), 62.7(E), 121.1(E), 218.3(E) M_\odot \).
Construction Technique: Fitting.
Equation of State: Ideal gas, radiation pressure.
Energy Transport: electron scattering opacity in radiative zones; convective core - variable \( \gamma \)-radiation pressure included.
Energy Sources: Carbon cycle-interpolation formula (82FH 1957).

Red Giants of Population II. I

Initial Composition: \( X = .900, Y = .099, Z = .001 \)
\( X = 0, Y = .999, Z = .001 \) in core as the evolution begins.
Mass: \( 1.3 M_\odot \) (E).
Construction Technique: Ideal gas, complete degeneracy in core (abrupt transition).
Energy Transport: The degenerate core is isothermal; electron scattering plus Kramers opacity in radiative zones.


Red Giants of Population II. II.
(Note in A. J., 66, 45).

Direct continuation of the paper above (Schwarzschild and Selberg 1962) through the Helium flash. Two interpolation formulae were used for the $3\alpha$ reaction at different temperatures.

An Evolutionary Sequence of Solar Models.

Initial Composition: $X = .75, Y = .235, Z = .015$ evolution is carried until $X = .423$ in the center.

Mass: $1 M_\odot$ (E).

Construction Technique: Fitting.

Equation of State: Ideal gas.

Energy Transfer: Convective Envelope (adiabatic convection $p = kT^{2.5}$); opacity in the radiative core is an interpolative fit to Keller Meyerott (10%).

Energy Sources: pp chain $(3^3\text{He} \rightarrow 3^2\text{He} \rightarrow 4^4\text{He})$ interpolation formula to fit $B^2FH$ 1957.

An Evolutionary Sequence of Solar Models with Revised Nuclear Reaction Rates.

Helium Content and Neutrino Fluxes in Solar Models.

Initial Composition: variable, $X = .71, Y = .27, Z = .02$ gives the best model for the sun.

Mass: $1 M_\odot$ (E).

Construction Technique: Fitting.
Equation of State: Ideal gas, partial degeneracy.

Energy Transport: Convective envelope \( P = XT^{2.5} \) at boundary; Interior opacity is a fit to the opacity tables of Keller-Meyerott (as in Iben and Ehrman 1962); Conduction has been included.

Energy Sources: Gravitational contraction; pp, CN chains - interpolation formula to fit Fowler 1960, Parker, Bahcall, Fowler 1964.

---


Initial Composition: \( X = 0.9, Y = 0.1 \) in convective envelope and radiative intermediate zone \((X_{CN} = 0.0005 \text{ or } 0.005);\) \( X = 0, Y = 1 \) in isothermal core.

Mass:

I. \((X_{CN} = 0.0005) 2.48, 1.48, 0.94, 0.58, 0.62, 0.99, 2.83, 2.20, 1.82, 1.09, 1.07, 1.26, 1.60, 2.49, 2.28, 2.29, 3.11 \text{ M}_\odot.\)

II. \((X_{CN} = 0.005) 2.20, 1.31, 0.84, 0.53, 0.56, 0.88, 2.52, 1.94, 1.61, 0.97, 0.96, 1.13, 1.43, 2.22, 2.03, 2.04, 2.78 \text{ M}_\odot.\)

Construction Technique: Fitting.

Equation of State: Ideal gas, partially degenerate electrons.

Energy Transport: Electron scattering opacity in radiative zones; \( p = E T^{2.5} \) in convective envelope.

Energy Sources: CN cycle in shell outside core, \( pT^{15} \) interpolation formula.

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Initial Composition: \( X = 0.70, Y = 0.27, Z = 0.03, X_{CN} = Z/2 \) throughout. Carried to the point where \( X = 0.07 \) in the core.

Mass: \( 30 \text{ M}_\odot \) (E).

Construction Technique: Fitting.
Equation of State: Ideal gas, radiation pressure.
Energy Transport: Electron scattering radiative opacity. Adiabatic convection in the core.
Energy Sources: Full CNO cycle - interpolation formula to Reeves 1963 good to 15% - sources restricted to the core.


As above (Stothers 1963) except gravitational contraction is added as an energy source when the hydrogen becomes exhausted in the core.

Evolution of O Stars, III. Helium Burning.

As above (Stothers, 1963, 1964). The distribution of energy sources varies in the Helium ignition, helium depletion and Helium exhaustion phases. Helium burning is added as an energy source.

The Semi-Convective Zone in Very Massive Stars.

As above (Stothers 1963-1966). The extent of the semi-convective zone and convective core are investigated during hydrogen burning.

Initial Composition: \( X = .70, Z = .03, X_{\text{CNO}} = Z/2 \).
Masses: 45, 60, 100, 200, 400, 1000 \( M_\odot \).

Stellar Models with Partially Degenerate Isothermal Cores.

Initial Composition: \( X = .90, Y = .09, Z = .01 \) in envelope. \( X = 0, Y = .99, Z = .01 \) in core.
Mass: \( 1(\text{E}), 1.2(\text{E}), 1.52(\text{E}), 2.0(\text{E}), 3.0(\text{E}), 4.0(\text{E}) \) \( M_\odot \).
Construction Technique: Fitting.
Equation of State: Ideal gas, partially degenerate electrons.
Energy Transport: Kramers opacity in outer radiative zones.
Energy Sources: CN cycle alone in shell at interface.
On the Properties of Stellar Models with Double Energy Sources, I.

Initial (envelope) Composition:
- I. $X = 0.900$, $Z = 0.001$, $X_{\text{CNO}} = (Z/7)/40$
- II. $X = 0.80$, $Z = 0.001$, $X_{\text{CNO}} = (Z/7)/40$
- III. $X = 0.9$, $Z = 0.001$, $X_{\text{CNO}} = (Z/2)/40$

Masses:
- I. 1.3, 1.0, 0.7 $M_\odot$
- II. 1.3 $M_\odot$
- III. 1.0 $M_\odot$

Construction Technique: Fitting.

Equation of State: Ideal gas.

Energy Transport: Opacity due to free-free transitions of H and He plus bound-free transitions of metallic ions in outer H envelope. Electron scattering opacity in the deeper envelope and intermediate radiative He zone, convective He core.

Energy Sources: CNO cycle at bottom of H-rich envelope, 3a reaction in the core.

Evolution of Very Massive Stars with Mass Loss.

Initial Composition: $X = 0.90$, $Z = 0.02$, $X_{\text{CNO}} = Z/3$.

Mass: 15.6, 46.8 $M_\odot$

Construction Technique: Fitting.

Equation of State: Ideal gas, radiation pressure.

Energy Transport: Electron scattering in radiative envelope; convective core.

Energy Sources: CNO Cycle.

Stellar Models with Isothermal Cores and Intermediate Convection Zones.

Massive Stars with Uniform Composition.

Initial Composition: Pure helium, or pure hydrogen.

Mass:

Construction Technique: Fitting, an approximate solution for massive stars with constant composition.
Equation of State: Ideal gas, radiation pressure.

Energy Transfer: Convection in core, electron scattering opacity in radiative zones.

Energy Sources: 3α interpolation formula for He model, pp, CN interpolation formula for "pure" hydrogen models.

The Evolution of Massive Stars Initially Composed of Pure Hydrogen.

Initial Composition: X = 1, Y = Z = 0, but there's already significant carbon by the time the model reaches the main sequence.

Mass: 40(E), 60(E), 80(E), 120(E) M_☉.

Construction Technique: Fitting.

Equation of State: Electron scattering opacity in the radiative envelope.


Some Models of Internal Structure of Subdwarfs.

Initial Composition: 1. X = .7, Y = .3, Z < 10^{-4}.
2. X = .7, Y = .2965, Z < 10^{-4}.
4. X = .7, Y = .299, Z = .001.
5. X = .7, Y = .292, Z = .001, X_C = .007.
7. X = .8, Y = .200, Z < 10^{-4}.
8. X = .8, Y = .196, Z < 10^{-4}, X_C = .004.
10. X = .99, Y = .01, Z < 10^{-4}.

Mass: 0.7, 0.9, 1.1, 1.3, 1.5, 1.7 M_☉.

Construction Technique: Fitting.

Equation of State: Ideal gas.

Energy Transport: Opacity is an interpolation to Keller-Meyerott (1955) or Reiz (1954) (12%) in radiative zones.
Energy Sources: CN cycle, pp chain-interpolation formula to B²FH corrected for He abundance.

On the Properties of Stellar Models with Double Energy Sources, II. Stellar Models of 1.3 M_☉ for Various CNO Contents.

Initial Composition:
1. X = .9, Y = .099, Z = .001, X_CNO = Z/7
2. X = .9, Y = .099, Z = .001, X_CNO = (Z/7)/40
3. X = .9, Y = .09, Z = .01, X_CNO = Z/7.

Mass: 1.3 M_☉.

See Suda and Virgopia, 1966.

C. Commentary on Stellar Models and Stellar Evolution

Nuclei of Planetary Nebula and the Late Stages of Stellar Evolution.

Diffusion in the Sun.

A Time Scale for the Mixing Process in S-Type Stars.

Approximate Evaluation of the Fermi-Dirac Functions.

Stabilité et évolution dans le voisinage de la séquence d'étoiles massives formées à partir d'hydrogène pur.


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Neutrino Production in Massive Helium Star Models.

    Evolution of Population II Stars.
    (Abstract).

    Cameron, eds., 231.

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    Stellar Evolution with Varying G.

    Some Observational Aspects of Stellar Evolution.

    A Note on the Onset of Helium Burning in Degenerate Stars.

    Solar Evolution with Varying G.
    (Abstract).

    On the Surface Boundary Conditions for Stars.

    Erratum, 1104.
    Massive Stars, Relativistic Polytropes, and Gravitational
    Radiation.

    The Outer Envelope of Giant Stars with Surface Convection
    Zone.

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    Advanced Stages in Stellar Evolution.

    Berechnung äussern Konvektionszonen mit nicht-lokalem
    Mischungswege.

    Evolution, R. F. Stein, A. G. W. Cameron, eds, 263.
    The Evolution of a Star of Seven Solar Masses.

    On the Nature of Strong Radio Sources.
A Stellar Model of Mixed Opacity and Its Variations with Mass, Chemical Composition, Opacity Coefficients, and Energy Generation Coefficients.

A Suggestion Concerning the Boundary Conditions of B Stars.

Massive Stars in Quasi-Static Equilibrium.

A Comparison between Homogeneous Stellar Models and the Observations.

The Surface Ratio of $^{14}$N to $^{12}$C during Helium Burning.

The Early Evolution of Stars between One and Three solar Masses.


Unified Origin and Evolution of Star Clusters.

Internal Structure of the Stars and Apsidal Motions.

The Interpretation of the Spectrum-Luminosity Diagram for the Pleiades.

Stellar Rotation and Stellar Evolution among Cepheids and Other Luminous Stars in the Hertzsprung Gap.

Expected Shape of the Mass Spectrum for Stars formed by Gravitational Contraction.

Kumar, S. S. (1964) Observ., 84, 18.
    An Attempted Explanation of the Horizontal Branch.

    L'evolution Stellaire.

    The Structure of the M Dwarf Stars I.

    Some Peculiar Stars Found Below the Main Sequence on the
    H-R Diagram.

    On the Late Stages of Stellar Evolution.

    Evolution of Stars Decreasing in Mass.

    An Evolutionary Interpretation of the H-R Diagram for the
    Orion-Nebula Cluster.

    Extended Main-Sequence of Some Stellar Clusters.

    Introductory Report (A survey of factors affecting stellar
    stability).

    A. G. W. Cameron, eds., 381.
    Mass Loss in the Planetary Nebula Stage.

    Solar Evolution and Brans-Dicke Cosmology.
    (Abstract in A. J., 70, 689).

    The Ages of M67, NGC 188, M 3, M 5, and M 13 according to
    Hoyles 1959 Models.

    Overshooting from Stellar Convective Cores.

    Stellar Evolution with Mass Loss.
    (Brief Note).

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    On Models of Non-Spherical Stars II. Rotating White Dwarfs.
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Neutron Stars I. Properties at Absolute Zero Temperature.

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Cosmic Ray Production by Vibrating Neutron Stars.

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   Comments on a Paper by A. Cameron.

   Oscillation Period of Neutron Stars.

   Lack of Homology in the Oscillations of Neutron Stars.

C. Collapsed Stars

   Gravitational Collapse and Relativistic Magnetohydrodynamics.

   Gravitational Collapse of Nonsymmetric and Rotating Masses.

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   Gravitational Collapse to a Small Volume.

   Collapse of Massive Stars.

   Relativistic Equations for Adiabatic, Spherically Symmetric
   Gravitational Collapse.

   Relativistic Equations for Spherical Gravitational Collapse with
   Escaping Neutrons.

   On the Problem of Gravitational Collapse.

   A Simple and Well-Adjusted Exterior Metric for a Collapsing
   or Anti-Collapsing Star.

   Adiabatic Fluid Spheres in General Relativity.

   An Analytical Solution for Gravitational Collapse with
   Radiation.
    Neutrino Luminosity of a Star in Gravitational Collapse in the
    General Theory of Relativity.

    Conversion into Neutrons of Matter under Collapse and the
    Neutrino Spectrum.

    Collapsed Stars in Binaries (Letter to editor).
VII. RAPIDLY CHANGING STARS

A. Stellar Stability

Stability of Polytropic Gas Spheres.

The Points of Bifurcation along the Maclaurin, the Jacobi, 
and the Jeans Sequences.

The Equilibrium and Stability of Darwin Ellipsoids.

The Calculation of Stellar Pulsation. 
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Binary systems with Decreasing Mass.

The Relativistic Instability of Polytropic Spheres.

On Schwarzschild's Criterion for the Stability of Gaseous Masses.

Thermal Instability in Non-Degenerate Stars.

Stellar Stability.

Critical Mass Limit and Stability of Some Relativistic Stellar 
Models.

On the Maximum Mass of Stable Stars.

Stability Criterion for Hydrostatic Equilibrium.
B. Variable Stars

Auto-Oscillations of Variable Stars.

The Influence of Hydrogen and He I Ionization Zones on Cepheid
Pulsation.

The Virial Theorem for Radiating and Gravitating Gaseous Systems.

The Pulsations of Models of δ-Cephei Stars.
(Reference in A. J., 66, 278).

Pulsating Instability of Cepheid Models.
(Abstract).

The Pulsating Models of Delta Cephei Stars, II.

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Simplified Models for Cepheid Instability.

Interpretation der Phasenbeziehungen zwischen Geswindigkeits-und
Leuchtkraft Kurve bei δ Cephei-Sternen.

On the Beat Phenomenon in δ Cephei Stars.

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Modes élevés d'oscillation radiale du Modèle standard et
stabilité vibrationelle des étoiles.

Effets de la convection sur la stabilité vibrationelle des
étoiles massives.

Stabilité vibrationelle des étoiles de Hélium pur.

A Speculation Concerning the Evolutionary State of Eta Carinae
(Note).


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   (Note).

   The Radial and Non-Radial Oscillations of Slowly Rotating 
   Gaseous Masses.

   Non-Radial Oscillations and the Beta Canis Majoris Stars.

   On the Exact Splitting of the Pulsation Modes in Connection 
   with the Beta Canis Majoris Stars. 
   (Letter to editor).

   Computer Program for Stellar Pulsation. 
   (Abstract).

   Non-Adiabatic Stellar Pulsation, I.

   Stellar Pulsation IV. A Semi-Theoretical Period-Luminosity 
   Relation for Classical Cepheids.

   Stellar Pulsation V. A Semi-Theoretical Period-Luminosity 
   Relation for Cepheids with Radiative Envelopes.

   A Preliminary Analysis of the Effectiveness of Second Helium 
   Ionization in Inducing Cepheid Instability in Stars.

   On Second Helium Ionization as a Course of Pulsational Instability 
   in Stars. 

   Comments on Zhevakin's Paper, "One Common Error in the 
   Theory of Stellar Variability".

   Self-Excited Pulsations in Stellar Envelopes. 
   (Abstract).

   Cameron, eds., 347. 
   Excitation and Growth of Radial Pulsations.


The Effects of Radiative Breaking on Free Periods of stellar Pulsations.

Color Excesses for Supergiants and Classical Cepheids III.
The Color-Magnitude Array for Cepheids in the Vicinity of the Sun.


Einige Bemerkungen über Pulsierende Gaskugeln.

Über pulsierende Gaskugeln: Antwort auf eine Kritik.

The Virial Tensor and its Application to Self-Gravitating Fluids.


Sur la forme Asymptotique des pulsations radiales adiabatiques d'une étoile.

The Propagation of Disturbances and Shock Waves in the Inside of Stars, I.

The Propagation of Shock Waves in the Inside of Stars, II.

Gravitational Effects of Luminosity.

On Convective Overstability.
(Abstract).

A Thermally Excited Non-Linear Oscillation.

Note on the Nature of ßC Ma Variables.
Radial Pulsations of the Polytrope \( n = 2 \).

The Calculation of Pulsation Constants for the RR Lyrae Stars in M3.

The Intrinsic Dispersion of the Period-Luminosity Relation of Classical Cepheids.

Cepheid Vibration.

Transfer of Mass in Close Binary Stars.

An Evolutionary-Significant Group of Eclipsing Variables.

Radial Oscillations of the Generalized Roche Model.

On the Periods of Long Period Variables in Globular Clusters.

On the Evolutionary State of \( \beta \) Cephei Stars.

Sur les conditions aux limites de la pulsation non-adiabatique d'étoile.

The Influence of Atmospheric Layers on the Pulsation of the Cepheid Variable.

Über die Stabilität der Radialen Pulsation der Sterne.

Anharmonic Pulsations of an Early Main-Sequence Star.


The Shock-Wave Model for the Population II Cepheids.
    Initial Motions of a Jacobi Ellipsoid Away from Its Unstable Form.

    The Dissipation of the Energy of Oscillation of a Pulsating Star.

    On the Calculation of Non-Adiabatic Stellar Pulsations by Use
    of a Discrete Model.

    On the Pulsation Theory of Stellar Variability V.

    The Pulsational Theory of Stellar Variability VI.

    Phase and Amplitude Variations in Radiation Traversing a Non-Adiabatic
    Envelope of a Pulsating Star.

    One Common Error in the Theory of Stellar Variability.

    The Incorrectness of Cox and Whitney's Simplified Criterion for
    the Pulsational Instability of a Star.

    Physical basis of the Pulsation Theory of Variable Stars.

C. Novae and Supernovae

    Californium 254, Iron 59, and Supernovae of Type I.

    On the Lower Mass Limit for Implosion Type Supernovae.

    Radioactivity in Supernovae Remnants.

    Hydrodynamic Origin of Cosmic Rays.


APPENDIX: TABLE OF STELLAR MODELS

<table>
<thead>
<tr>
<th>M/M☉</th>
<th>Initial Composition</th>
<th>Reference</th>
<th>Date</th>
</tr>
</thead>
<tbody>
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<td>&lt;1.4</td>
<td>He⁴, C¹², Mg²⁴, Si²⁸, S³², or Fe⁵⁶ plus an equilibrium composition of these</td>
<td>503, Hamada, et al.</td>
<td>1961</td>
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<td>0.04</td>
<td>I X = .90, Y = .009, Z = .01 II X = .62, Y = .35, Z = .03</td>
<td>530, Kumar</td>
<td>1963</td>
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<td>530, Kumar</td>
<td>1963</td>
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<td>530, Kumar</td>
<td>1963</td>
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<td>530, Kumar</td>
<td>1963</td>
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<td>530, Kumar</td>
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<td>0.269</td>
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<td>526, Kaminisi</td>
<td>1960</td>
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<td>0.31 E</td>
<td>Y = 1</td>
<td>488, Cox, et al.</td>
<td>1964</td>
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<td>0.35</td>
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<td>488, Cox, et al.</td>
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<td>see p 94</td>
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<td>Y = 1.0</td>
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<td>.53</td>
<td>X = .9, Y = .1 in convective envelope and radiative in intermediate zone</td>
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<td>X = 0, Y = 1 in isothermal core $X_{CN} = .005$</td>
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<td>$X_{CN} = .005$ see above</td>
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<td>.58</td>
<td>$X_{CN} = .0005$ see above</td>
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<td>.59 E</td>
<td>X = .38, Z = .015</td>
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<td>.6</td>
<td>X = .999, Z = .001 or .01</td>
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<td>$X_{CN} = .005$ see above</td>
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</table>
\[ X = 0.65, \quad X_{\text{CNO}} = Z/2 = 10^{-3},\]
\[ 10^{-4}, 10^{-5} \]

\[ X = 0.38, \quad Z = 0.015 \]

\[ I \quad X = 0.7, \quad Y = 0.3, \quad Z < 10^{-4}, \quad X_C = 0 \]

\[ II \quad X = 0.7, \quad Y = 0.2965, \quad Z < 10^{-4}, \quad X_C = 0 \]

\[ III \quad X = 0.7, \quad Y = 0.293, \quad Z < 10^{-4}, \quad X_C = 0.0035 \]

\[ IV \quad X = 0.7, \quad Y = 0.299, \quad Z = 0.001, \quad X_C = 0 \]

\[ V \quad X = 0.7, \quad Y = 0.292, \quad Z = 0.001, \quad X_C = 0.007 \]

\[ VI \quad X = 0.7, \quad Y = 0.297, \quad Z = 0.003, \quad X_C = 0 \]

\[ VII \quad X = 0.8, \quad Y = 0.20, \quad Z < 10^{-4}, \quad X_C = 0 \]

\[ VIII \quad X = 0.8, \quad Y = 0.196, \quad Z < 10^{-4}, \quad X_C = 0.004 \]

\[ IX \quad X = 0.8, \quad Y = 0.192, \quad Z < 10^{-4}, \quad X_C = 0.008 \]

\[ X \quad X = 0.99, \quad Y = 0.01, \quad Z < 10^{-4}, \quad X_C = 0 \]

\[ .7 E \quad X = 0.90, \quad Y = 0.10, \quad Z = 0.001 \]

\[ .7 E \quad X = 0.90, \quad Y = 0.10, \quad Z = 0.001, \quad X_{\text{CN}} = Z/2 \]

\[ .7 \quad \text{Envelope: } X = 0.9, \quad Y = 0.099, \quad Z = 0.001, \quad X_{\text{CN}} = (Z/7)/40 \]

\[ \text{Core: } X = 0, \quad Y = 0.999, \quad Z = 0.001 \]

\[ .70 E \quad X = 0.65, \quad X_{\text{CNO}} = Z/2 = 10^{-3}, \quad 10^{-4}, \quad 10^{-5} \]

\[ X = 0.90, \quad X_{\text{CNO}} = Z/2 = 10^{-4} \]

\[ .718 \quad X = 0, \quad Y = 0, \quad Z = 1, \quad X_{\text{CN}} \sim 0.02 \text{ or } 0.03 \]

\[ .71 \quad Y = 1 \]

501, Faulkner, et al. 1966
482, Bodenheimer 1965
568, Varsavsky, et al. 1962
510, Hayashi, et al. 1962
513, Hayashi, et al. 1963
563, Suda, et al. 1965
501, Faulkner, et al. 1966
490, Deinzer, et al. 1965
488, Cox, et al. 1964
X = .65, X_{CNO} = Z/2 = 10^{-3}, 10^{-4}, 10^{-5} 
X = .90, X_{CNO} = Z/2 = 10^{-4} 

Y = 1.0 

see p 95 

see p 95 

see p 95 

see p 95 

I  Y = 1 
II  Y = 1 for 0 \leq M/M_\odot \leq .85 
III  Y = 1 for 0 \leq M/M_\odot \leq .8 
II, X = .9, Y = .099, Z = .001 
III in envelope 

X = .57 or .77, Z = .03 

X = .67, Z = .03 

X = .66, Z = .0264 

see p 95 

see p 95 

X_{CN} = .005 see p 95 

X = .6, Z = .02, X_{CN} = .18Z 

see p 95 

X_{CN} = .005 see p 95 

X = .7, Z = .02, X_{CN} = .18Z 

see p 96 

X = .57 or .77, Z = .03 

X = .67, Z = .03 

X = .6, Z = .02, X_{CN} = .19Z 

see above 

501, Faulkner, et al. 1966 

545, Rose 1966 

497, Divine 1965 

490, Deinzer, et al. 1965 

491, Demarque 1960 

492,  

493, Demarque 1961 

538, Osaki 1963 

495, Demarque, et al. 1964 

495, Demarque, et al. 1964 

482, Bodenheimer 1965 

497, Divine 1965 

490, Deinzer, et al. 1965 

556, Shimoda, et al. 1958 

520, Iben et al. 1962 

490, Deinzer, et al. 1965 

556, Shimoda, et al. 1958 

520, Iben, et al. 1962 

568, Varsavsky, et al. 1962 

495, Demarque, et al. 1964 

495, Demarque, et al. 1964 

539, Pearce, et al. 1965 

539, Pearce, et al. 1965
see p 97
see p 97
see p 97
see p 97
$X_{CN} = .0005$ see p 95
see p 97
see p 97
$X_{CN} = .005$ see p 95
$X = 0, Y = 0, Z = 1,$
$X_{CN} \sim .02$ or .03
$X_{CN} = .005$ see p 95
$Y = 1.0$
$X = .75, Y = .249, Z = .001$
$X_{CN} = .0005$ see p 95
$X = .75, Y = .23, Z = .02$
$X = .76, Y = .2375, Z = .0025$
$X = .85, Y = .1475, Z = .0025$
$X = .93, Y = .0675, Z = .0025$
$X = .99, Y = .0075, Z = .0025$
$Z$ is all C-N
$X = .75, Y = .235, Z = .015$
see p 95
$X = .995, Y = .003, Z = .002$
$X = .90, Y = .09, Z = .01$
(envelope)
$X = 0, Y = .99, Z = .01$
(core)
$Y = 1$
$Y = 1$

537, Pearce, et al. 1965
539, Pearce, et al. 1965
539, Pearce, et al. 1965
539, Pearce, et al. 1965
556, Shimoda, et al. 1958
539, Pearce, et al. 1965
539, Pearce, et al. 1965
556, Shimoda, et al. 1958
490, Deinzer, et al. 1965
556, Shimoda, et al. 1958
489, Deinzer, et al. 1964
506, Haselgrove, et al. 1950
556, Shimoda, et al. 1958
532, Limber 1958
480, Blackler 1953
553, Sears 1959
491, Demarque 1960
492,
533, Massevich, et al. 1960
562, Suda, et al 1960
486, Cox, et al. 1961
487, Cox, et al. 1961
1.0 see 492, Demarque 1960 p 95
1.0 X = 1
1.0 Y = .999, Z = .001
1.0 E X = .999, Y = 0, Z = .001
1.0 E Y = 1
1.0 E Z = .02 for X = .78, .76, .74, .72, .70
Z = .025 for X = .74, .72, .70, .68, .66
Z = .030 for X = .72, .70, .68, .66, .64
Z = .035 for X = .70, .68, .66, .64
Z = .040 for X = .68, .66, .64
1.0 X = .57 or .77, Z = .03
1.0 E X = .67, Z = .03
1.0 X = .68, Y = .276, Z = .044,
X_{CN} = .0091
1.0 E .68 \leq X \leq .81, Z = .04
1.0 E X = .90, Y = .099, Z = .001
1.0 E Variable-X = .71, Y = .27
Z = .02 gives best model
1.0 X = .739, Y = .240, Z = .021
X_o = 4.618 \times 10^{-3}, X_{N} = .97 \times 10^{-3}, X_0 = 1.0715 \times 10^{-2}
1.00 X = .6, Z = .02, X_{CN} = .19 Z
1.0 E X = .66, Z = .0264
1.0 E X = 0, Y = .999, Z = .001
1.0 see p 96
1.0 X = .9, Y = .099, Z = .001
X_{CNO} = (Z/2)/40
1.0  E  
X = .65, X_{CNO} = Z/2 = 10^{-3}, 10^{-4}, 10^{-5} CNO
X = .90, X_{CNO} = Z/2 = 10^{-4}
population II stars

1.01  
X = .75, Y = .24, Z = .01

1.02  
X = .75, Y = .249, Z = .001

1.05  
X = .7, Z = .02, X_{CN} = .18 Z

1.05  
X = .7, Z = .01 X_{CN} = .19 Z

1.06  
X = .99, Y = .009, Z = .001

1.06  
see above (1.05)

1.07  
X = .7, Z = .01, X_{CN} = .18 Z

1.07  
X_{CN} = .0005 see p 95

1.07  
see above (1.05)

1.08  
see above (1.05)

1.085  
see above (1.05)

1.09  
X_{CN} = .0005 see p 95

1.09  
X = .75, Y = .24, Z = .01

1.09  
X = .75, Y = .24, Z = .01

1.09  
see above (1.05)

1.095  
see above (1.05)

1.10  
see p 96

1.10  
X = .57, .67, or .77, Z = .03

1.10  
X = .7, Z = .01, .02, X_{CN} = .19 Z

1.110  
X = .7, Z = .02, X_{CN} = .19 Z

1.112  
X = .75, Z = .015, X_{CN} = .18 Z

1.120  
see above (1.110)

501, Faulkner, et al.  1965

557, Smak  1960

506, Haselgrove, et al.  1959

506, Haselgrove, et al.  1959

520, Iben, et al.  1962

539, Pearce, et al.  1965

506, Haselgrove, et al.  1959

539, Pearce, et al.  1965

520, Iben, et al.  1962

556, Shimoda, et al.  1958

539, Pearce, et al.  1965

539, Pearce, et al.  1965

539, Pearce, et al.  1965

556, Shimoda, et al.  1958

506, Haselgrove, et al.  1959

518, Hoyle  1959

539, Pearce, et al.  1965

539, Pearce, et al.  1965

568, Varsavsky, et al.  1962

495, Demarque, et al.  1964

539, Pearce, et al.  1965

539, Pearce, et al.  1965

520, Iben, et al.  1962

539, Pearce, et al.  1965

539, Pearce, et al.  1965
1.13 $X_{CN} = .005$, see p 95
1.13 see p 100 (1.110)
1.135 see p 100 (1.110)
1.140 see p 100 (1.110)
1.150 see p 100 (1.110)
1.16 E $X = .75, Y = .249, Z = .001$
1.17 $X = .75, Y = .249, Z = .001$
1.175 $X = .8, Z = .01$
1.19 $X = .75, Y = .24, Z = .01$
1.2 E $X = .9, Y = .1, X_{CN} = .0005$
1.20 $X = .99, Y = .009, Z = .001$
1.2 E see p 96
1.20 E $X = .999, Y = 0, Z = .001$
$X = .99, Y = 0, Z = .01$
$X = 1, Y = 0, Z = 0$
$X = .749, Y = .25, Z = .001$
1.2 $X = .57, .67, .77, Z = .03$
1.20 $X = .8, Z = .02$
$X = .8, (X_{CN} = .19 Z), Z = .01$
$X = .7, Z = .02$
1.2 E $X = .66, Z = .0264$
1.2 E $X = .899, Y = .100, Z = .001$
$X = .891, Y = .099, Z = .01$
1.21 $X = .6, Z = .02$
1.25 $X = .99, Y = .009, Z = .001$
1.25 $X = .8, Z = .02$
1.25 $Y = 1.0$
1.250 $X = .8, Z = .02$,
$X = .7, (X_{CN} = .19 Z), Z = .02, .01$
$X = .6, Z = .02$
556, Shimoda, et al. 1958
539, Pearce, et al. 1965
539, Pearce, et al. 1965
539, Pearce, et al. 1965
539, Pearce, et al. 1965
518, Hoyle 1959
506, Haselgrove, et al. 1959
520, Iben, et al. 1962
506, Haselgrove, et al. 1959
527, Kippenhahn, et al. 1958
506, Haselgrove, et al. 1959
562, Suda, et al. 1960
494, Demarque, et al. 1963
495, Demarque, et al. 1964
539, Pearce, et al. 1965
482, Bodenheimer 1965
531, Kung, et al. 1965
520, Iben, et al. 1962
506, Haselgrove, et al. 1959
520, Iben, et al. 1962
488, Cox, et al. 1964
539, Pearce, et al. 1965
<table>
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<tr>
<th>1.25</th>
<th>X = 0, Y = .999, Z = .001</th>
<th>497, Divine</th>
<th>1965</th>
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<td>1.25</td>
<td>X = .9,.65,</td>
<td>500, Faulkner</td>
<td>1966</td>
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<tr>
<td></td>
<td>$X_{\text{CNO}} = .5Z = 10^{-5}$</td>
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<tr>
<td>1.25 E</td>
<td>X = .65, $X_{\text{CNO}} = .5Z = 10^{-3}$</td>
<td>501, Faulkner, et al.</td>
<td>1966</td>
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<tr>
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<td>X = .90, $X_{\text{CNO}} = .5Z = 10^{-4}$</td>
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<tr>
<td>1.256</td>
<td>X = .7, Z = .02</td>
<td>520, Iben, et al.</td>
<td>1962</td>
</tr>
<tr>
<td>1.26</td>
<td>$X_{\text{CN}} = .0005$ see p 95</td>
<td>556, Shimoda, et al.</td>
<td>1958</td>
</tr>
<tr>
<td>1.27 E</td>
<td>X = .9309, Y = .0666, Z = .0025</td>
<td>505, Haselgrove, et al.</td>
<td>1958</td>
</tr>
<tr>
<td>1.29</td>
<td>X = .75, Y = .24, Z = .01</td>
<td>506, Haselgrove, et al.</td>
<td>1959</td>
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<tr>
<td>1.30 E</td>
<td>X = .90, Y = .099, Z = .001</td>
<td>551, Schwarzschild, et al.</td>
<td>1962</td>
</tr>
<tr>
<td>1.30 E</td>
<td>X = .75, Y = .22, Z = .03</td>
<td>552, Schwarzschild, et al.</td>
<td>1962</td>
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<tr>
<td>1.3</td>
<td>see p 96</td>
<td>558, Varsavsky, et al.</td>
<td>1962</td>
</tr>
<tr>
<td>1.3</td>
<td>X = .57,.67,.77, Z = .03</td>
<td>495, Demarque, et al.</td>
<td>1964</td>
</tr>
<tr>
<td>1.3 E</td>
<td>X = .90, Y = .099, Z = .001</td>
<td>504, Härm, et al.</td>
<td>1964</td>
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<tr>
<td></td>
<td>X = .90, Y = .090, Z = .01</td>
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<tr>
<td>1.30</td>
<td>X = .8, Z = .02,.01, $X_{\text{CN}} = .19$ Z</td>
<td>539, Pearce, et al.</td>
<td>1955</td>
</tr>
<tr>
<td>1.3</td>
<td>see p 96, also X = .8, Z = .001</td>
<td>563, Suda, et al.</td>
<td>1956</td>
</tr>
<tr>
<td></td>
<td>$X_{\text{CNO}} = (Z/7)/40$</td>
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<tr>
<td>1.3</td>
<td>X = .9, Z = .01,.001,</td>
<td>569, Virgopia, et al.</td>
<td>1966</td>
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<td></td>
<td>$X_{\text{CNO}} = Z/7$</td>
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<td></td>
<td>$X_{\text{CNO}} = (Z/7)/40$</td>
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<td>1.303</td>
<td>X = .6, Z = .02, $X_{\text{CN}} = .18$ Z</td>
<td>520, Iben, et al.</td>
<td>1962</td>
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<td>1.31</td>
<td>$X_{\text{CNO}} = .005$, see p 95</td>
<td>556, Shimoda, et al.</td>
<td>1958</td>
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<tr>
<td>1.310</td>
<td>X = .8, Z = .01, $X_{\text{CN}} = .19$ Z</td>
<td>539, Pearce, et al.</td>
<td>1965</td>
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<td>1.315</td>
<td>see above (1.31)</td>
<td>539, Pearce, et al.</td>
<td>1965</td>
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<td>1.320</td>
<td>see above (1.31)</td>
<td>539, Pearce, et al.</td>
<td>1965</td>
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<td>1.330</td>
<td>see above (1.31)</td>
<td>539, Pearce, et al.</td>
<td>1965</td>
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1.34  \( X = .75, Y = .249, Z = .001 \)

1.340  see p 102 (1.31)

1.35  \( X = .99, Y = .009, Z = .001 \)

1.35 E  \( X = .99, Y = .009, Z = .001 \)

1.350  \( X = .8, Z = .02, .01, X_{CN} = .19 Z \)

1.354  \( X = .7, Z = .02 \)

1.360  \( X = .8, Z = .02, X_{CN} = .19 Z \)

1.365  see above (1.360)

1.370  see above (1.360)

1.380  see above (1.360)

1.390  see above (1.360)

1.40  \( X = .75, Y = .24, Z = .01 \)

1.40  \( X = .8, Z = .02, .01, X_{CN} = .19 Z \)

1.420  \( X = .8, Z = .01, X_{CN} = .18 Z \)

1.43  \( X_{CN} = .005 \) see p 95

1.43  \( X = .75, Y = .249, Z = .001 \)

1.44  \( X = .75, Z = .015, X_{CN} = .18 Z \)

1.45  see above (1.360)

1.46  \( X = .75, Y = .24, Z = .01 \)

1.47  \( X = .99, Y = .009, Z = .001 \)

1.47  \( X = .7, Z = .01, X_{CN} = .18 Z \)

1.48  \( X_{CN} = .0005 \) see p 95

1.48  \( X = .73, Y = .25, Z = .02 \)

1.5 E  \( X = .68, Y = .31, Z = .01 \)

1.5  see p 96

506, Haselgrove, et al.  1959

539, Pearce, et al.  1965

506, Haselgrove, et al.  1959

518, Hoyle  1959

539, Pearce, et al.  1965

520, Iben, et al.  1962

539, Pearce, et al.  1965

539, Pearce, et al.  1965

539, Pearce, et al.  1965

539, Pearce, et al.  1965

539, Pearce, et al.  1965

506, Haselgrove, et al.  1959

539, Pearce, et al.  1965

506, Haselgrove, et al.  1959

520, Iben, et al.  1962

556, Shimoda, et al.  1958

506, Haselgrove, et al.  1959

520, Iben, et al.  1962

539, Pearce, et al.  1965

506, Haselgrove, et al.  1959

506, Haselgrove, et al.  1959

520, Iben, et al.  1962

556, Shimoda, et al.  1958

479, Bennick, et al.  1965

514, Henyey, et al.  1959

568, Varsavsky, et al.  1962
<table>
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<tr>
<th>1.5</th>
<th>$Y = 1.0$</th>
<th>488, Cox, et al.</th>
<th>1964</th>
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<tr>
<td>1.5</td>
<td>$X = .7, .8, Z = .02, .01$</td>
<td>539, Pearce, et al.</td>
<td>1965</td>
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<td>1.5</td>
<td>$X = .6, Z = .02$</td>
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<td>1.5</td>
<td>$X_{CN} = .19 Z$</td>
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<td>1.506</td>
<td>$X = 0, Y = .999, Z = .001$</td>
<td>497, Divine</td>
<td>1965</td>
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<td>1.52</td>
<td>$X = .7, Z = .02, X_{CN} = .18 Z$</td>
<td>520, Iben, et al.</td>
<td>1962</td>
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<td>1.52</td>
<td>$X = .75, Y = .24, Z = .01$</td>
<td>506, Haselgrove, et al.</td>
<td>1959</td>
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<td>1.52</td>
<td>$X = .75, Y = .249, Z = .001$</td>
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<tr>
<td>1.52 E</td>
<td>$X = .75, Y = .23, Z = .02$</td>
<td>519, Hoyle</td>
<td>1969</td>
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<td>1.52 E</td>
<td>see p 96</td>
<td>562, Suda, et al.</td>
<td>1963</td>
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<td>1.538</td>
<td>$X = 0, Y = 0, Z = 1, X_C \sim .02$ or $0.03$</td>
<td>490, Deinzer, et al.</td>
<td>1965</td>
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<td>1.563</td>
<td>$X = .6, Z = .02, X_{CN} = .18 Z$</td>
<td>520, Iben, et al.</td>
<td>1962</td>
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<td>1.581</td>
<td>$X = .8, Z = .02, X_{CN} = .18 Z$</td>
<td>520, Iben, et al.</td>
<td>1962</td>
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<td>1.596</td>
<td>$X = .75, Z = .015, X_{CN} = .18 Z$</td>
<td>520, Iben, et al.</td>
<td>1962</td>
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<td>1.6</td>
<td>$X_{CN} = .0005$ see p 95</td>
<td>556, Shimoda, et al.</td>
<td>1958</td>
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<td>1.6</td>
<td>$X = .99, Y = .009, Z = .001$</td>
<td>506, Haselgrove, et al.</td>
<td>1959</td>
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<td>1.6</td>
<td>see p 102 (1.31)</td>
<td>539, Pearce, et al.</td>
<td>1965</td>
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<td>1.61</td>
<td>$X_{CN} = .005$ see p 95</td>
<td>556, Shimoda, et al.</td>
<td>1958</td>
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<td>1.61</td>
<td>$X = .75, Y = .249, Z = .001$</td>
<td>506, Haselgrove, et al.</td>
<td>1959</td>
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<td>1.623</td>
<td>$X = 0, Y = 0, Z = 1, X_C \sim .02$ to $0.03$</td>
<td>490, Deinzer, et al.</td>
<td>1965</td>
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<td>1.645</td>
<td>see above</td>
<td>490, Deinzer, et al.</td>
<td>1965</td>
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<td>1.7</td>
<td>see p 96</td>
<td>568, Varsavsky, et al.</td>
<td>1962</td>
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<td>1.706</td>
<td>$X = .8, Z = .01, X_{CN} = .18 Z$</td>
<td>520, Iben, et al.</td>
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<td>1.74</td>
<td>$X = .99, Y = .009, Z = .001$</td>
<td>506, Haselgrove, et al.</td>
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<td>1.750</td>
<td>$X = .8, .7, Z = .02, .01$</td>
<td>539, Pearce, et al.</td>
<td>1965</td>
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<td>$X = .6, Z = .02$</td>
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<td>$X_{CN} = .19 Z$</td>
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<td>1.794</td>
<td>$X = 0.8, Z = 0.02, X_{CN} = 0.18 Z$</td>
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<td>1.811</td>
<td>$X = 0.7, Z = 0.01, X_{CN} = 0.18 Z$</td>
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| 1.82  | $
u_i / \nu_c = 1.0, 1.5788, 2.5, 2.6667$ |
| 1.82  | $X_{CN} = 0.005$ see p 95 |
| 1.86  | $X = 0.6, Z = 0.02, X_{CN} = 0.18 Z$ |
| 1.866 | $X = 0.7, Z = 0.02, X_{CN} = 0.18 Z$ |
| 1.87  | $X = 0.75, Z = 0.015, X_{CN} = 0.18 Z$ |
| 1.94  | $X_{CN} = 0.005$ see p 95 |
| 1.94  | $X = 0.75, Y = 0.249, Z = 0.001$ |
| 1.97  | $X = 0.75, Y = 0.24, Z = 0.01$ |
| 2.0 E | see p 98 |
| 2.0 E | $X = 0.68, Y = 0.31, Z = 0.01$ |
| 2.0 E | see p 96 |
| 2.0   | $Y = 1$ |
| 2.0   | $Y = 1$ |
| 2.0   | $X = 1$ |
| 2.0 E | $Y = 1$ |
| 2.0   | $X = 0.596, Z = 0.02$ |
| 2.00  | see p 104 (1.75) |
| 2.0 E | $X = 0.596, Z = 0.02, X_{CN} = 0.20 Z$ |
| 2.0   | $X = 0, Y = 0.999, Z = 0.001$ |
| 2.02  | $X = 0.8, Z = 0.01, X_{CN} = 0.18 Z$ |
| 2.03  | $X_{CN} = 0.005$ see p 95 |
| 2.04  | $X_{CN} = 0.005$ see p 95 |
| 2.07  | $X = 0.99, Y = 0.009, Z = 0.001$ |
| 2.10  | $X = 0.8, Z = 0.02, X_{CN} = 0.18 Z$ |
| 520, Iben, et al. | 1962 |
| 520, Iben, et al. | 1962 |
| 515, Hitotuyanagi, et al. | 1958 |
| 556, Shimoda, et al. | 1958 |
| 520, Iben, et al. | 1962 |
| 520, Iben, et al. | 1962 |
| 520, Iben, et al. | 1962 |
| 556, Shimoda, et al. | 1958 |
| 506, Haselgrove, et al. | 1959 |
| 506, Haselgrove, et al. | 1959 |
| 480, Blackler | 1958 |
| 514, Henyey, et al. | 1959 |
| 562, Suda, et al. | 1960 |
| 486, Cox et al. | 1961 |
| 487, Cox, et al. | 1961 |
| 498, Ezer | 1961 |
| 488, Cox, et al. | 1964 |
| 476, Auman, et al. | 1965 |
| 539, Pearce, et al. | 1965 |
| 477, Auman | 1965 |
| 497, Divine | 1965 |
| 520, Iben, et al. | 1962 |
| 556, Shimoda, et al. | 1958 |
| 556, Shimoda, et al. | 1958 |
| 506, Haselgrove, et al. | 1959 |
| 520, Iben, et al. | 1962 |
| 2.135 | X = .75, Z = .015, X\textsubscript{CN} = .18 Z |
| 2.172 | X = .7, Z = .01, X\textsubscript{CN} = .18 Z |
| 2.20  | X\textsubscript{CN} = .005,.0005 see p 95 |
| 2.22  | X\textsubscript{CN} = .005 see p 95 |
| 2.26  | X = .6, Z = .02, X\textsubscript{CN} = .18 Z |
| 2.28  | X\textsubscript{CN} = .0005 see p 95 |
| 2.280 | X = .7, Z = .02, X\textsubscript{CN} = .18 Z |
| 2.29  | X\textsubscript{CN} = .0005 see p 95 |
| 2.292 | Y = 1 |
| 2.3 E | I-C\textsuperscript{12} = .0042, C\textsuperscript{13} = 5.4(-5), N = 1.45(-3), O = 1.31(-2) |
|      | II-C\textsuperscript{12} = .0016, C\textsuperscript{13} = 5.4(-5), N = 5.49(-3), O = 1.31(-2) |
|      | III-C\textsuperscript{12} = .0016, C\textsuperscript{13} = 5.4(-5), N = 1.359(-2), O = 5(-3) |
|      | IV-C\textsuperscript{12} = .0028, C\textsuperscript{13} = 3.6(-5), N = 9.67(-4), O = 8.74(-3) |
|      | X = .68, Y = .29 for all 4 cases |
| 2.32  | X = .8, Z = .01, X\textsubscript{CN} = .18 Z |
| 2.43  | X = .75, Y = .249, Z = .001 |
| 2.46  | X = .99, Y = .009, Z = .001 |
| 2.48  | X\textsubscript{CN} = .0005 see p 95 |
| 2.49  | X\textsubscript{CN} = .0005 see p 95 |
| 2.5   | X = .7, Y = .28, Z = .02, X\textsubscript{CN} = .19 Z |
| 2.5   | X = .596, Z = .02 |
| 2.52  | X\textsubscript{CN} = .005 see p 95 |
| 2.63  | X = .8, Z = .02, X\textsubscript{CN} = .18 Z |
| 2.68  | X = .99, Y = .009, Z = .001 |

520, Iben, et al. 1962
520, Iben, et al. 1962
556, Shimoda, et al. 1958
556, Shimoda, et al. 1958
520, Iben, et al. 1962
556, Shimoda, et al. 1958
520, Iben, et al. 1962
556, Shimoda, et al. 1958
489, Deinzer, et al. 1964
481, Bodenheimer, et al. 1963
520, Iben, et al. 1962
506, Haselgrove, et al. 1959
506, Haselgrove, et al. 1959
556, Shimoda, et al. 1958
556, Shimoda, et al. 1958
478, Bahng 1964
476, Auman, et al. 1965
556, Shimoda, et al. 1938
520, Iben, et al. 1952
506, Haselgrove, et al. 1959
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<tr>
<th>X_{CN}</th>
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<th>year</th>
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<td>see p 95</td>
<td>2.78</td>
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<tr>
<td>0.0005</td>
<td>see p 95</td>
<td>2.83</td>
<td></td>
</tr>
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<td>Z = 0.01</td>
<td>2.850</td>
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</tr>
<tr>
<td>0.7</td>
<td>Z = 0.02</td>
<td>2.864</td>
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556, Shimoda et al.  | 1958 |
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506, Haselgrove, et al. | 1959 |
485, Cimino, et al.  | 1963 |
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497, Divine          | 1965 |
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506, Haselgrove, et al. | 1959 |
514, Henyey, et al.  | 1959 |
476, Auman, et al.   | 1965 |
519, Hoyle           | 1960 |
506, Haselgrove, et al. | 1959 |
489, Deinzer, et al. | 1964 |
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| Y = 1.0 | 5.0  | 486, Cox, et al. | 1961 |
| Y = 1.0 | 5.0  | 487, Cox, et al. | 1961 |
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| X = .708, Z = .02 | 5.0 E | 522, Iben | 1966 |
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487, Cox, et al.
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14.8 E  \[ Y = 1.0 \]
14.8  \[ Y = .999, Z = .001 \]
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15.6 E  \[ X = .90, Y = .08, Z = .02, X_{CN} = Z/3 \]
15.6 E  \[ X = .90, Y = .08, Z = .02, X_{CNO} = Z/3 \]
15.6  \[ X = .90, Y = .08, Z = .02, X_{CNO} = Z/7 \]
16.0 E  see p 98
19.4  \[ X = 0, Y = 0, Z = 1, X_C \sim .02 \text{ to } .03 \]
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502, Giannone, et al. 1965
489, Deinzer, et al. 1964
497, Divine 1965
524, Iben 1966
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546, Sakashita, et al. 1953
507, Hayashi, et al. 1959
510, Hayashi, et al. 1962
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564, Tanaka 1966
529, Kotok 1966
480, Blackler 1938
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534, Nagaratnam, et al. 1961
550, Schwarzschild, et al. 1958


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X = 0.70, \ Y = 0.05, \quad X_{\text{CNO}} = Z/7
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X = 0.75, \ Y = 0.23, \ Z = 0.02
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X = 0.75, \ Y = 0.24, \ Z = 0.01
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\[
\text{see p 98}
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Y = 1.0
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Y = 0.999, \ Z = 0.001
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X = 0.75, \ Y = 0.24, \ Z = 0.01
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514, Henyey, et al. 1959

558, Stothers 1963

559, Stothers 1964

560, Stothers 1966

529, Kotok 1966

519, Hoyle 1960

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480, Blackler 1958

489, Deinzer, et al. 1964

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567, Van der Borght 1964

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547, Sakashita, et al. 1959

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