12 Appendix A: Constants, Acronyms, and Standard Variables

Table 12.1. Table of Constants

Name	Symbol	cgs value	useful alternative	SI value
Bohr radius	a_o	5.29×10^{-9} cm	0.529 Å	5.29×10^{-11} m
Speed of light	c	3×10^{10} cm/s		3×10^{8} m/s
Electronic charge	e	4.8×10^{-10} statcoul		1.6×10^{-19} Coul
Planck constant	h	6.63×10^{-27} erg-sec		6.63×10^{-34} J-sec
Boltzmann constant	k_B	1.6×10^{-12} erg/eV	1.6×10^{-16} J/keV	1.38×10^{-23} J/K
Electron rest mass	m_e	9.11×10^{-28} g		9.11×10^{-31} kg
Proton mass	m_p	1.67×10^{-24} g	$1836m_e$	1.67×10^{-27} kg
Stefan-Boltzmann	σ	5.67×10^{-5} ergs/(cm^2 s deg^4)	1.03×10^{5} W/(cm^2 eV^4)	5.67×10^{-8} W m^{-2} K^{-4}

Table 12.2. Table of Acronyms

Acronym	Represents
ASE	Amplified spontaneous emission
CPA	Chirped pulse amplification
DPP	Distributed phase plate
DPR	Distributed polarization rotator
ICF	Inertial confinement fusion
LTE	Local thermodynamic equilibrium
NLTE	Nonlocal thermodynamic equilibrium
RT	Rayleigh Taylor
KH	Kelvin Helmholtz
RM	Richtmyer Meshkov
RPP	Random phase plate
SBS	Stimulated Brillouin scattering
SN	Supernova
SRS	Stimulated Raman scattering
SSD	Smoothing by spectral dispersion
exp[]	Equivalent to $e^{[]}$

Table 12.3. Table of standard variables

Name	Symbol
Atomic weight (average)	A
Vector potential	$\boldsymbol{A}$
Atwood number	A_n
Area of capsule	A_c
Area of laser spots	A_L
Area of walls of hohlraum	A_w
Magnetic field	$\boldsymbol{B}$
Thermal intensity	$B(T)$
Thermal spectral intensity	$B_\nu(T)$
Isentropic sound speed	c_s
Specific heat at const vol	c_V
Small vortex diameter	d
Element of area	$d\boldsymbol{A}$
Critical to solid density distance	D
Electron charge	e
Electric field	$\boldsymbol{E}$
Spectral kinetic energy	$E(k)$
Themal energy density	E_{BB}
Energy released by fusion	E_{fus}
Hydrogen ionization energy	E_H
Electric field of laser beam	E_L
Total radiation energy density	E_R
Energy in Marshak wave	E_w
Spectral radiation energy density	E_ν
Energy difference between ionization states j and k	E_{jk}
Electron total energy	$\mathcal{E}_e$
Electron rest mass energy	$\mathcal{E}_o$
Ion total energy	$\mathcal{E}_i$
Thermal flux	F_{BB}
Electron free energy	F_e
Electromagnetic force density	$\boldsymbol{F}_{EM}$
Lorentz force	$\boldsymbol{F}_{\bar{L}}$
Radiative energy flux	$\boldsymbol{F}_R$
Total radiation flux	F_R
Photon flux	$\boldsymbol{F}_\gamma$
Spectral radiation flux	F_ν
Eddington factor	$f_\nu = p_\nu / E_\nu$
Distribution function	$f(v)$
"Gravitational" acceleration	g
Laser irradiance	I_L
Total intensity	I_R
Laser irradiance in units of 10^{xx} W/cm2	I_{xx}
Spectral intensity	I_ν

Table 12.3. (continued)

Name	Symbol
Current density	$\boldsymbol{J}$
Richardson number	J_r
Total mean intensity	J_R
Transverse current density	$\boldsymbol{J}_t$
Mean spectral intensity	J_ν
Riemann invariants	J_+ or J_-
Wave number	k
Wave vector	$\boldsymbol{k}$
Coefficients in Maxwell's equations	k_1, k_2, k_3
Scale length of a profile	L
Eddy diameter	ℓ
Compton mean free path	ℓ_C
Mach number	M
Upstream Mach number	M_u
Internal Mach number	M_int
Fusion fuel mass	m_f
Mass ablation rate	$\dot{m}$
Shock normal	$\boldsymbol{n}$
Electron density	n_e
Ion density	n_i
Critical density	n_c
Scalar fluid pressure	p
Total scalar pressure	$\tilde{p}$
Electron momentum	$\boldsymbol{p}_\mathrm{e}$
Fermi degenerate pressure	p_F
Scalar radiation pressure	p_R
General pressure tensor	$\underline{\boldsymbol{P}}$
Ablation pressure	P_abl
Power threshold for relativistic self-focusing	P_sf
Turbulent energy dissipation	P_t
Radiation spectral pressure tensor	$\underline{\boldsymbol{P}}_\nu$
Thermal Heat flux	$\boldsymbol{Q}$
Radiation Strength parameter	Q
Spitzer–Harm heat flux	Q_SH
Free-streaming heat flux	Q_FS
Internal energy	R
Gas constant $p/(\rho T)$	R
Ion sphere radius	R_o
Radiation strength parameter	R_r
Poynting flux	$\boldsymbol{S}$
Specific entropy	s
Specific entropy of electrons	s_e
Source of quantity Q	S_Q
Spectral source function	S_ν
Time	t

Table 12.3. (continued)

Name	Symbol
Temperature	T
Immediate post-shock temperature	T_2 or T_s
Fermi-degenerate temperature	T_d
Electron temperature	T_e
Effective temperature	T_eff
Ion temperature	T_i
Temperature corresponding to a radiation flux	$T_\mathrm{min}, T_\mathrm{eff}$
Energetic electron temperature	T_hot
Precursor temperature	T_p
Radiation temperature	T_R
Immediate postshock plasma (mainly electron) temperature	T_s
Hohlraum wall temperature	T_w
Fluid velocity	$\boldsymbol{u}$
Zeroth-order fluid velocity	U
Characteristic velocity for scaling arguments	U
First-order components of fluid velocity	$\boldsymbol{u}_1 = (u, v, w)$
Kolmogorov velocity scale	u_k
Particle velocity	$\boldsymbol{v}$
Velocity difference between frames of reference	$\boldsymbol{v}$
Phase velocity	v_p
Oscillating velocity of electron in light wave	$\boldsymbol{v}_\mathrm{os}$
Electron thermal velocity	v_th
Rocket velocity (or capsule velocity)	V
Exhaust velocity	V_ex
Vertical component of velocity	w
Vortex rotational velocity	w
Eddy rotational velocity	w_e
Marshak wave scaling variable	W
Mag. Energey den.	W_B
Electric energy density	W_E
Space	x
Marshak wave penetration depth	x_M
Fusion yield	Y
Ionic charge (average)	Z
Albedo	α
Various angles	α
Fraction of incoming photons ionized	α_i
Various angles	β
Relativistic velocity (v/c)	β
Various angles	χ
Coeff of thermal diffusivity	χ
Electron momentum	χ_e

Table 12.3. (continued)

Name	Symbol
Jet cooling parameter	χ_{j}
Rosseland-mean opacity	χ_{R}
Spectral total opacity	χ_{ν}
Specific internal energy	ϵ
Total specific internal energy density	$\tilde{\epsilon}$
Downstream emissivity	ϵ_{d}
Specific internal electron energy	ϵ_{e}
Fermi energy	ϵ_{F}
Specific internal ion energy	ϵ_{ii}
Specific kinetic ion energy	ϵ_{ik}
Upstream emissivity	ϵ_{u}
Efficiency of ideal rocket	ϵ_{R}
Various angles	ϕ
Fusion burn fraction	ϕ
Phase of a wave	ϕ
Phase experienced by an electron	ϕ_{e}
Scalar electric potential	$\varPhi$
Polytropic index	γ
Relativistic γ	γ_r
Instability growth rate	γ_o
Strong coupling parameter	$\varGamma$
Flux of quantity Q	$\varGamma_Q$
various angles and fractions	η
x-ray conversion efficiency	η
Kolmogorov length scale	η_{k}
Spectral emissivity	η_{ν}
Spectral scattering emissivity	$\eta_{\nu\mathrm{sc}}$
Spectral thermal emissivity	$\eta_{\nu\mathrm{th}}$
Absorption opacity	κ
Total coefficient of heat conduction	$\tilde{\kappa}$
Opacity of thin layer using cooling function	κ_{astro}
Thermal bremsstrahlung absorption coefficient	κ_{b}
EM wave absorption coefficient	κ_{EM}
Specific Planck mean opacity	κ_{m}
Planck mean opacity	κ_{P}
Radiative coefficient of heat conduction	κ_{rad}
Thermal coefficient of heat conduction	κ_{th}
Spectral absorption opacity	κ_{ν}
Wavelength of a wave	λ
Vortex characteristic scale	λ
Taylor microscale	λ_{T}
Debye length	λ_{D}
Electron Debye length	λ_{De}

Table 12.3. (continued)

Name	Symbol
Ion Debye length	λ_{Di}
Mean free path	λ_{mfp}
Wavelength in microns	λ_{μ}
Astrophysical cooling function	Λ
Chemical potential	μ
Classical chemical potential	μ_c
Vortex characteristic scale	λ
Atomic mass per charge (A/Z)	μ_{e}
Electron–ion collision rate	ν_{ei}
Optically thin cooling rate	ν
Kinematic viscosity	ν
Radiation frequency	ν
Extinction rate	ν_{e}
Cooling rate normalization for thin layer	ν_{rad}^{*}
Cooling rate more general	ν_1
Cooling rate using cooling function	ν_{astro}
Radiation cooling rate for thin layer	ν_{rad}
Kinematic photon viscosity	ν_{rad}
Scaling variable $n_{\mathrm{e}}/T_{\mathrm{e}}^{3/2}$	θ
Degeneracy parameter	Θ
Mass density	ρ
Charge density	ρ_c
Density of Q	ρ_{Q}
Scattering opacity	σ_{s}
Spectral scattering opacity	σ_{ν}
Viscosity stress tensor	$\underline{\boldsymbol{\sigma}}_{\nu}$
Kolmogorov time scale	τ_{k}
Optical depth at frequency ν	τ_{ν}
Optical depth	τ
Wave frequency	ω
Laser light frequency	ω_o
Normalized frequency	ω_{n}
Electron plasma frequency	ω_{pe}
Ion plasma frequency	ω_{pi}
Scattered light frequency	ω_{s}
Irradiance conversion by hohlraum	ξ
General similarity variable	ξ
Gravitational potential	Ψ

13 Appendix B: Sample *Mathematica* Code

This notebook provides an example of a computational math derivation of the basic shock relations.

- **Begin by loading packages we may want for plotting**

```
<< Graphics`MultipleListPlot`
<< Graphics`Graphics`
<< NumericalMath`ListIntegrate`
$TextStyle =
 {FontWeight → "Bold", FontFamily → "Helvetica", FontSize → 12}

{FontWeight → Bold, FontFamily → Helvetica, FontSize → 12}
```

- **First suppose γ does not change. Write the balance equations as quantities equal to zero**

```
eq1 = ρ1 u1 - ρ2 u2
eq2 = ρ1 u1^2 + p1 - ρ2 u2^2 - p2
eq3 = (p1 u1 + ρ1 ε1 u1 + ρ1 u1^3/2) - (p2 u2 + ρ2 ε2 u2 + ρ2 u2^3/2)
```

- **Analysis: 3 equations.**
  First want relations between pressure and density.
  Use EOS to eliminate ϵ.
  Then use first two equations to eliminate u1 and u2.

- **The next step is the first example of a pattern replacement. This is a key technique for doing algebra in *Mathematica* without being forced to define dummy variables. It saves a lot of confusion.**

```
eq3a = eq3 /. {ε1 → p1/(ρ1 (γ - 1)), ε2 → p2/(ρ2 (γ - 1))}
```

```
cond1 = Solve[{eq1 == 0}, u2]
(* Here we solve an equation to create a condition giving the
  value of a variable. It is useful to use a systematic
  notation for this. Then we substiture the results *)
eq4 = eq2 /. cond1[[1]]
eq5 = (eq3a /. cond1[[1]])
```

- **The next two steps are why this is a pain to do on paper.
  We solve for u1 and then substitute in the energy equation, and finally solve for p2.
  If you try it on paper, the algebra is a lot easier using 1/ρ as a variable.**

```
cond2 = Solve[eq4 == 0, u1]
eq6 = eq5 /. cond2
```

```
cond3 = Solve[eq6 == 0, p2]
```

```
cond3[[2]]
```

```
prat = Simplify[(p2 /. cond3[[2]]) / p1]
 (* creating a normalized ratio of p2/p1 *)
```

```
pratv = Simplify[prat /. {ρ1 → 1 / V1, ρ2 → 1 / V2}]
```

- **The above two results are the standard expressions for the pressure ratio.
  Next find the density ratio.**

```
cond4 = Solve[eq6 == 0, ρ2]
```

```
rhorat = Simplify[(ρ2 /. cond4[[1]]) / ρ1]
 (* rhorat is the ratio ρ2/ρ1  *)
```

```
eq7 = ρ2 / ρ1 - rhorat
```

- **Here we created an equation for the density ratio, eq7, which is equal to zero. That lets us proceed to find other solutions, for example involving Mach number. This follows:**

```
cond5 = Solve[eq4 == 0, p2]
```

```
cond6 = Solve[eq7 == 0 /. cond5[[1]], ρ2]
```

```
cond7 = Simplify[cond6 /. p1 → ρ1 cs^2 / γ]
 (* using the standard definition of sound speed *)
```

```
cond8 = Simplify[(cond7[[2]] /. u1 → Mu cs)]
 (* Mu is the upstream Mach number *)
```

```
rhorat2 = (ρ2 /. cond8[[1]]) / ρ1
 (* get the standard expression for the density ratio *)
```

```
prat2 = Simplify[prat /. ρ2 → ρ1 rhorat2]
 (* get the standard expression for the pressure ratio *)
```

```
Trat = Collect[Simplify[prat2 / rhorat2], Mu]
 (* develop an expression for the temperature ratio *)
```

```
test = Simplify[Trat /. Mu → 1] (* check sensibility *)
```

```
p2a = Simplify[p1 (prat2 /. Mu^2 → (ρ1 us^2 / (γ p1)))]
```

```
p2b = ρ2/(A mp) kB (Z + 1) T /. ρ2 → ρ1 rhorat2
p2b = p2b /. Mu^2 → (ρ1 us^2 / (γ p1))
```

```
cond9 = Solve[p2b - p2a == 0, T]
```

```
T2 = Collect[T /. cond9[[1]], us]
```

```
Ten = T2 /. kB -> 1
```

```
Tenig = Ten /. γ → 5 / 3
```

```
(* With p1 = 0, this is the "standard" result  *)
```

Notebook to do Fermi distributions and related calculations

- **Begin by loading useful packages**

```
<< Graphics`MultipleListPlot`
<< Graphics`Graphics`
<< NumericalMath`ListIntegrate`
$TextStyle =
 {FontWeight → "Bold", FontFamily → "Helvetica", FontSize → 12}
```

- **Sections that follow**
  1. Fermi degenerate distributions
  2. Classical vs Degenerate density and pressure calculations

- **1. First section produces fermi degenerate plot, using the expression in the text for the electron distribution function**

```
f = (Exp[-eFermi/kT] + 1)/(Exp[(-eFermi + en)/kT] + 1)
g = Exp[-en / kT]
f1 = Simplify[f /. {en → α eFermi}]
g1 = Simplify[g /. {en → α eFermi}]
f2 = Simplify[f1 /. {eFermi → (1/β) kT}]
g2 = Simplify[g1 /. {eFermi → (1/β) kT}]
```

```
g1 = Plot[{f2 /. β → .01, f2 /. β → 1, f2 /. β → 10, g2 /. β → 10},
   {α, 0, 10}, PlotRange → {{0, 10}, {0, 1.1}}, Frame → True,
   PlotStyle → {{Thickness[0.008]}, {Thickness[0.008]},
     {Thickness[0.008]}, {Thickness[0.015], GrayLevel[.5]}}]
```

```
Export["fermi distributions.eps", g1, "EPS"]
```

```
LinearLogPlot[
 {f2 /. β → .01, f2 /. β → 1, f2 /. β → 5, g2 /. β → 5},
 {α, 0, 10}, PlotRange → {{0, 10}, {.2, 1.1}}]
```

■ 2. Classical vs Degenerate density and pressure calculations

▪ Basic relations

```
efermi = (6 π^2/2)^(2/3) (h/(2 π))^2 ne^(2/3)/(2 me)
Θ1 = (kB Te) / efermi (* this is Θ  *)
Θψ = PowerExpand[Θ1 /. ne → (ψ Te^(3/2))]
coefΘψ =
 Θψ /. {ψ → 1, me →  9.11 10^-28, h →  6.63 10^-27, kB → 1.6 10^-12}
ΘF = PowerExpand[Θ1 /. ne → (Te^(3/2) (4 π (2 me kB)^(3/2))/h^3 Fonehalf)]
```

Some quantities relevant to results in the book by Lindl

```
neLindl = 0.25/(2.5 1836 9.11 10^-28)
```

```
eFermiLindl = 7.9 * neLindl/10^23
```

```
pFermiLIndl = 9.9 (0.25/2.5)^(5/3)
```

```
ΘLindl = Θ1 /. {me →  9.11 10^-28, h →  6.63 10^-27, kB → 1.6 10^-12,
    Te → 11.5/11604 0.001, ne → neLindl}
```

```
(* the range of ψ of interest is 10^14 to 10^26  *)
(* so the range of Θ is *)
coefΘψ/(10^14)^(2/3) (* to *)
coefΘψ/(10^26)^(2/3)
```

```
(* i.e. 0.001 to 10^6  *)
```

This next plot shows why this is the range

```
g2 = LogLogPlot[{ni, 10 ni, 20 ni, 40 ni, 80 ni}, {ni, 10^19, 10^24},
  PlotRange → {{10^19, 10^24}, {1. 10^20, 1. 10^26}}, Frame → True]
```

```
N[10^19 / 1000^(3/2)]
```

- **This part calculates μ/(kB Te) for Θ = T/Td**

```
Solve[ Θψ == Θ, ψ]
μclassΘ = Log[PowerExpand[
   (h^3 / (2 (2 π me kB)^(3/2)) Θ) /. Θ → (ψ /. Solve[ Θψ == Θ, ψ])][[1]]]
μfermiΘ = PowerExpand[((3 π^2)^(2/3) (h / (2 π))^2 1/(2 me kB) Θ^(2/3)) /.
   Θ → (ψ /. Solve[ Θψ == Θ, ψ])][[1]]
```

```
Θcrit = N[ Θ /. Solve[μclassΘ == 0, Θ][[1]]]
```

```
(* range of μ us *)
N[μclassΘ /. Θ → 10^6] (* to *)
N[μfermiΘ /.  Θ → .001]
```

```
Θclass = Θ /. Solve[μ1 == μclassΘ, Θ][[1]]
Θfermi = Θ /. Solve[μ1 == μfermiΘ, Θ][[1]]
```

- **One desires to generate plots showing how the chamical potential is related to the temperature. This is difficult both because one must construct tables of results from numerical integrals and because *Mathematica* does not happily do this. The following aproach works.**
  One has to
  (a) set up the integral,
  (b) do the integral to fill a table (here using finer resolution as the potential approaches zero),
  (c) arrange the arrays of numbers as needed for plotting, and
  (d) make the plots.

```
Clear[μ1]
eq100 = ((3 / 2) HIntegrate[Sqrt[x] / (1 + Exp[x - μ1]), {x, 0, 200}])^(-2/3)
eq100 /. {μ1 → 15, HIntegrate → NIntegrate}
```

```
eq101 = ((3 / 2) HIntegrate[Sqrt[x] / (1 + Exp[x - μ1]), {x, 0, μend}])^(-2/3)
```

```
eq102 = ((3 / 2) HIntegrate[Sqrt[x] / (1 + Exp[x - μ1]), {x, 0, 2 μ1}])^(-2/3)
```

```
t1 = Table[{-μ1, N[θclass], N[θfermi],
    eq101  /. {HIntegrate → NIntegrate, μend → Max[200, 2 μ1] }}
  , {μ1, -21, -2, 1}];
t2 = Table[{-μ1, N[θclass], N[θfermi],
    eq101  /. {HIntegrate → NIntegrate, μend → Max[200, 2 μ1] }}
  , {μ1, -1.99, -.01, .01}];
tneg = Join[t1, t2];
thetaplot = Transpose[tneg][[4]];
μplot = Transpose[tneg][[1]];
neglist = Transpose[Append[{thetaplot}, μplot]];
classplotneg = Transpose[tneg][[2]];
negclass = Transpose[Append[{classplotneg}, μplot]];
Null
```

```
g1 = LogLogListPlot[neglist, PlotRange → {{10^-3, 10^3}, {0.1, 20}},
    PlotJoined → True,
    Frame → True, PlotStyle → {Thickness[0.005]}];
g2 = LogLogListPlot[negclass,
    PlotRange → {{10^-3, 10^3}, {0.1, 20}},
    PlotJoined → True, Frame → True, PlotStyle →
     {Thickness[0.008], GrayLevel[0.5], Dashing[{0.02, 0.02}]}];
g3 =
 Show[
  g1,
  g2]
```

```
g4 = LogLogListPlot[neglist, PlotRange → {{10^2, 10^6}, {0.1, 25}},
  PlotJoined → True, Frame → True]
g5 =
  LogLogListPlot[negclass, PlotRange → {{10^2, 10^6}, {0.1, 25}},
   PlotJoined → True, Frame → True, PlotStyle →
    {Thickness[0.008], GrayLevel[0.5], Dashing[{0.02, 0.02}]}];
g6 =
 Show[
  g4,
  g5]
```

- **The above did the work for negative chemical potential. Now do it again for positive chemical potential**

```
t3 = Table[{μ1, N[Θclass], N[Θfermi],
   eq101  /. {HIntegrate → NIntegrate, μend → Max[200, 2 μ1] }}
  , {μ1, .1, 20, .1}];
t4 = Table[{μ1, N[Θclass], N[Θfermi],
   eq101  /. {HIntegrate → NIntegrate, μend → Max[200, 2 μ1] }}
  , {μ1, 30, 1000, 10}];
tpos = Join[t3, t4];
thetaplot = Transpose[tpos][[4]];
μplot = Transpose[tpos][[1]];
poslist = Transpose[Append[{thetaplot}, μplot]];
posclass = Transpose[Append[{Transpose[tpos][[2]]}, μplot]];
posfermi = Transpose[Append[{Transpose[tpos][[3]]}, μplot]];
```

```
g11 =
  LogLogListPlot[poslist, PlotRange → {{10^-3, 10^3}, {0.1, 1000}},
   PlotJoined → True, Frame → True,
   PlotStyle → {Thickness[0.005]}];
g12 = LogLogListPlot[posclass,
   PlotRange → {{10^-3, 10^3}, {0.1, 1000}},
   PlotJoined → True, Frame → True, PlotStyle →
    {Thickness[0.008], GrayLevel[0.5], Dashing[{0.02, 0.02}]}];
g13 = LogLogListPlot[posfermi,
   PlotRange → {{10^-3, 10^3}, {0.1, 1000}},
   PlotJoined → True, Frame → True,
   PlotStyle → {Thickness[0.008], Dashing[{0.02, 0.02}]}];
g14 = Show[g11, g12, g13]
```

Now one can explort the plots for the two regimes, to be combined in graphics software

```
Export["muvsthetaneg.eps", g3, "EPS"]
Export["muvsthetapos.eps", g14, "EPS"]
```

■ Now do the pressure integral, for pe/(ne kB Te)

```
eqF32 = HIntegrate[x^1.5/(1 + Exp[x - μ1]), {x, 0, μend}]
eqF12 = HIntegrate[x^0.5/(1 + Exp[x - μ1]), {x, 0, μend}]
eq200 = (2/3) (eqF32/eqF12)
```

- **Can leave out $\mu < 0$ as this is obviously ~ 1.**

```
p1 = Table[
  {μ1, eq200 /. {HIntegrate → NIntegrate, μend → Max[200, 2 μ1]}},
  {μ1, 0.11, 99.01, .1}]
```

```
g100 = LogLogListPlot[p1, PlotRange → {{0.1, 100}, {0.5, 40}},
  PlotJoined → True, Frame → True]
```

```
Export["p vs μ fermi.eps", g100, "EPS"]
```

- **From this calculation, at large μ one has p/(ne kB Te) = (2/5) μ/(kB Te)**
  But in the degenerate regime μ/(kB Te) = 1/Θ . So p = pF = (2/5) μ ϵF

■ Compare electron and ion energy contributions in classical regime.

```
jmax = IntegerPart[0.63 √Te]
eion = Sum[i^2 EH, {i, 1, jmax}] /. EH → 13.6
eelec = (3/2) 0.63 √Te Te (* Te and EH in eV here *)
```

```
gener = LogLogPlot[{eion, eelec},
  {Te, 5, 1000}, PlotPoints → 1000, Frame → True]
```

```
Export["energy comparison.eps", gener, "EPS"]
```

14 Appendix C: A List of the Homework Problems

Homework 2.1

One approach to deriving the Euler equations is to identify the density, flux, and sources of mass, momentum, and energy and then to use (2.5). Do this for a polytropic gas and then simplify the results to obtain (2.1) through (2.3).

Homework 2.2

Linearize the Euler equations to derive (2.7) and (2.8). Find appropriate divisors to make these equations nondimensional and discuss which terms are smaller than others. Then derive (2.9).

Homework 2.3

Take the actual, mathematical Fourier transform of (2.9) to find (2.10).

Homework 2.4

Substitute, for the density in (2.9), the actual, mathematical Fourier transform of the spectral density $\tilde{\rho}(\boldsymbol{k}, \omega)$. Show how the result is related to (2.10).

Homework 2.5

Derive (2.14) from (2.1), (2.2), and (2.4).

Homework 2.6

Generalize the above derivation to a plasma with an arbitrary number of ion species, each of which may have a distinct temperature.

Homework 2.7

Derive (2.63).

Homework 2.8

Derive a replacement for (2.65), keeping an appropriate version of the drag term at the end of (2.62).

Homework 2.9

Find the sizes and directions of the particle orbits. Explain from fundamental laws of electromagnetics why their direction is as it is. Show pictorially why the $\boldsymbol{E} \times \boldsymbol{B}$ drift moves particles in the same direction.

Homework 3.1

Inertial fusion designs typically involve the compression of DT fuel to about 1,000 times the liquid density of 0.25 g cm^{-3}. Assuming that this compression is isentropic and that the fuel remains at absolute zero, determine the energy per gram required to compress this fuel. Compare this to the energy per gram required to isentropically compress the fuel to this same density, assuming the fuel is an ideal gas whose final temperature is to be the ignition temperature of 5 keV.

Homework 3.2

Argue conceptually that the contribution of the denominator in (3.16) at large $\mu/(k_B T_e)$ is a step function. Evaluate this integral numerically to determine how rapidly it becomes a step function as $\mu/(k_B T_e)$ increases.

Homework 3.3

Show, in the limit as $T_e \rightarrow 0$, that $n_e \epsilon_e = (3/5) n_e \epsilon_F$.

Homework 3.4

Derive 3.24 and 3.26 and discuss their differences.

Homework 3.5

Make plots comparing Z_{bal} from (3.35) with the estimate $20\sqrt{T_e}$ as a function of T_e, for ion densities of 10^{19}, 10^{21}, and 10^{23} cm^{-3}. Discuss the results.

Homework 3.6

Carry out the evaluation in (3.2.9) and compare the result to Z_{bal}, for $T_e = 1$ keV, $Z_{\text{nuc}} = 30$, and $n_i = 10^{21}$cm^{-3}.

Homework 3.7

Plot the ratio of ΔE to the ionization energy versus Z_i from 1 to 80 for ion densities of of 10^{19}, 10^{21}, 10^{23}, and 10^{25} cm^{-3}. Discuss the results.

Homework 3.8

Derive (3.73).

Homework 3.9

The value of R used here ignores the internal energy in excited states (as well as the energy lost by radiation during ionization, which would properly have to be treated by more general equations). Again assuming hydrogenic ions, estimate what fraction of the internal energy is present in excited states, and how this varies with Z.

Homework 4.1

Add a gravitational force density and gravitational potential energy to (4.2) and (4.3) and derive the modified jump conditions.

Homework 4.2

Suppose that during the shock transition significant energy is lost by radiation. Write down the modified jump conditions.

Homework 4.3

Determine from energy arguments how to generalize (4.20) for a two-species plasma.

Homework 4.4

Appendix B shows a derivation of (4.10)–(4.15). For $\gamma_1 = \gamma_2$, derive (4.18) and (4.20). Using a computational mathematics program is suggested.

Homework 4.5

Derive from (4.10) and (4.12) a general expression for T_2, valid for weak and strong shocks, for $\gamma_1 = \gamma_2$. Express the result in physically clear parameters, so the relation among the terms is evident. Check your result by finding it as a limit of (4.19) and by finding (4.20) as a limit from it.

Homework 4.6

Evaluate the entropy variation of (4.24) as the Mach number approaches 1.

Homework 4.7

Derive (4.28)–(4.31).

Homework 4.8

Derive (4.34) and (4.35).

Homework 4.9

Derive (4.42). This requires thinking about which frame of reference one is working in, a key element in all such problems.

Homework 4.10

Determine the equations and derive the behavior of the simpler case in which a shock is incident on a stationary wall. Let state 0 be the state of the unshocked fluid, state 1 be that of the once-shocked fluid, and state 2 be the state of the reshocked fluid produced when the shock reflects from the wall.

Homework 4.11

For the simpler case in which $p_1 = p_4 = 0, \rho_1 = \rho_4,$ and$\gamma_1 = \gamma_4 = \gamma$, which is not a bad approximation for many flyer plate collisions, solve (4.44)–(4.1.50) to find the pressure and velocity of the shocked material.

Homework 4.12

Show that the conservation of mass in fact requires $x \geq -c_s t$ in (4.61) and (4.62).

Homework 4.13

Obtain (4.74) from (4.73).

Homework 4.14

Sketch the C_+ and C_- characteristics in a fluid flowing uniformly with velocity u.

Homework 4.15

Plot the minimum density and pressure in the rarefaction as a function of U. Discuss the meaning of the plots. Reasonable normalizations are recommended.

Homework 4.16

Show that this type of analysis produces $\alpha = 1/2$ for cylindrical blast waves and $\alpha = 2/3$ for planar blast waves

Homework 4.17

Find the coefficients α for cylindrical and planar momentum-conserving snowplows.

Homework 4.18

Derive (4.95)–(4.97).

Homework 4.19

Derive (4.106)–(4.108).

Homework 4.20

Use a computational mathematics program to integrate these equations to find and plot the profiles, and to evaluate Q, for a cylindrical case. Apply this to find the behavior of a lightning channel produced by a deposited energy of 10^{10} ergs/cm.

Homework 4.21

Assuming that a strong shock reaches an interface beyond which the density (ρ_4) is 0.1 times the density of the shocked material to the left of the interface (ρ_1), solve for the profiles of the fluid parameters in the rarefaction that results.

Homework 4.22

Assuming that $\gamma_1 = \gamma_4$ (or not, if you wish), derive (4.116) from (4.44)–(4.52) by letting p_3 approach p_1 as the definition of the transition to a rarefaction. Hint: This one is not easy. Taking a limit will be necessary and the approach to the solution will matter.

Homework 4.24

An entertaining aspect of this specific problem is that it is one case where the traditional model in which shocks are driven by moving pistons does not produce correct qualitative behavior. Consider a rarefaction as it approaches a piston that is moving forward at a constant velocity. What will happen?

Homework 4.25

To obtain these results, one must evaluate the equations in cylindrical polar coordinates. Beginning with the first two Euler equations, carry out this evaluation.

Homework 4.26

Thus, a property of uniform flow is that $u_r = -\partial u_\phi/\partial\phi$ in any cylindrical polar coordinate system. Landau and Lifshitz use a geometric argument to demonstrate this. Instead, demonstrate this using a vectorial argument. (Hint: Begin by taking dot products of unit vectors along r and ϕ with an arbitrary velocity vector.)

Homework 5.1

Consider a system with water above oil as just described. Suppose there is an small, sinusoidal ripple on the surface. Find the vertical profile of the force density between the lower and upper boundaries of the ripple for a region of denser fluid and for a region of less-dense fluid. Discuss the comparison of the two fluids and the shape of the force density profile.

Homework 5.2

The final relation in (5.22) is significant for our specific application, in which one needs to integrate, across an interface, equations that contain discontinuous quantities along with derivatives of discontinuous quantities. By treating the delta function and the step function as limits of appropriate functions (see a mathematical methods book), prove this relation.

Homework 5.3

Find the solution for the velocity profiles and the growth rate for the RT instability for two uniform, constant density fluids that are confined by two planar surfaces each a distance d from the interface, which is accelerated at constant g.

Homework 5.4

The discussion above (5.43) shows that $\tilde{n} = (n/\sqrt{kg})\sqrt{\tilde{k}}$. This would suggest that it might make more sense to separate the meaning of the axes more cleanly by using $\tilde{\delta} = (n/\sqrt{kg})$ and $\tilde{k} = [(k^2\nu)/\sqrt{gk}]^{2/3}$ as the two variables. Recast this equation in terms of these new variables, solve it, and plot the real roots from $\tilde{k} = 0$ to 2. Discuss the results and compare them to $n = \sqrt{A_n gk}$.

Homework 5.5

Derive (5.44) and (5.45) from (5.41). Comment on the nature of the terms that have been dropped.

Homework 5.6

Find the plane-wave solutions to (5.48) and discuss their behavior.

Homework 5.7

Consider an exponential density profile that decreases in the direction of the acceleration, g, as $\rho = \rho_o e^{-z/L}$, and thus is the opposite of the case analyzed above. Apply the RT instability analysis to find n for this case. Discuss the results.

Homework 5.8

Carry out this calculation and find (5.66). Then find the limits when (a) $k_p \to 0$ and $k_x L \gg 1$ and (b) when $A_n = 0$ and $L_p = 0$. Compare these with previous results in the chapter.

Homework 5.9

Work out the linear theory to find an expression for the growth rate for the case of a density gradient that extends for a finite distance between two layers of constant density.

Homework 5.10

By operating on (5.82) and (5.84), create two scalar differential equations that can be subtracted to eliminate terms involving p. Compare the resulting differential equation to (5.21) and discuss.

Homework 5.11

If we take the point of view that the modulations of interest are proportional to e^{int}, then we would insist on finding negative imaginary n in order to have growth of the modulations, as opposed to damping, in time. However, this should give us pause because the complex representation is only a mathematical convenience while the physical quantities are real. Considering the real, physical quantities, what is the significance of finding positive or negative imaginary n. (The chapter in Jackson, which introduces waves, may be of some help regarding the connection of real physical quantities and a complex representation.)

Homework 5.12

Suppose β is small enough that terms involving β in (5.127) can be dropped. Determine whether the two boundaries seen in Fig. 5.10 ever cross, completely eliminating the instability.

Homework 5.13

Analyze the shock conditions for a small-amplitude ripple and show that the change due to the ripple in the $\hat{z}$ component, relative to that from a planar shock, is second order in the ripple amplitude [i.e., generalize (5.130)].

Homework 5.14

Solve (5.133) through (5.136) to find the ratio of α, η, and χ to β. Plot the results for various values of γ and comment on what you observe.

Homework 5.15

Evaluate the small-angle limit of the equations for a shock at an oblique interface with a density decrease, and produce a plot similar to Fig. 5.19 for this case.

Homework 5.16

Consider the qualitative behavior of the postshock interface when there is a rarefaction but $\chi < 0$. Redraw Fig. 5.19 for this case. Discuss the evolution of the interface.

Homework 5.17

Develop (5.144) and (5.145) from the equations in Chap. 2.

Homework 5.18

Derive (5.147) through (5.149).

Homework 5.19

To be more precise about this point, one should recognize that what moves with the fluid is the vorticity passing through a surface S. Prove this by taking the time derivative of the integral of $\boldsymbol{\omega} \cdot d\boldsymbol{S}$ over a surface S that moves with the fluid and may change its shape in time. Relate the result to (5.154). Hint: The key here is the evaluation of the partial derivative in time of the surface as a contour integral involving the edge of the surface.

Homework 5.20

Obtain (5.153) through (5.155) from the momentum equation.

Homework 6.1

Integrate the thermal intensity over 2π steradians to find the total radiation power per unit area from a surface at temperature T.

Homework 6.2

Using the particle treatment of the radiation, derive an expression for the total radiation momentum density, and show that it equals $\boldsymbol{F}_R/c^2$.

Homework 6.3

Derive (6.14).

Homework 6.4

From the uncertainty principle, the spectral width in frequency, $\Delta\nu$, of an emission line is roughly the inverse of the decay time. For a typical decay time of 1 ns, find the normalized spectral width $\Delta\nu/\nu$, for emission lines in the visible and in the soft x-ray with a photon energy of 100 eV.

Homework 6.5

Derive (6.27)

Homework 6.6

Take moments of the radiation transfer equation to derive (6.38) and (6.40).

Homework 6.7

Beginning with (6.47), derive Eqs. (6.48) to (6.51).

Homework 6.8

Derive (6.56). Discuss the result.

Homework 6.9

Demonstrate this.

Homework 6.10

Given these relations, show that the radiative transfer equation is relativistically invariant.

Homework 6.11

Derive (6.73), (6.74), and (6.75). Discuss the limits on v/c for this specific description if the emission and absorption are dominated by a) continuum emission or b) line emission.

Homework 6.12

Rework (6.78) into the form of a conservation equation and discuss the meaning of the terms that result.

Homework 7.1

Carry out the calculations just described and compare the behavior of pure hydrogen as opposed to C_1H_1 (used in Fig. 7.1).

Homework 7.2

Derive the dispersion relation for isothermal acoustic waves from the Euler equations. That is, demand constant temperature and see what happens.

Homework 7.3

Figure 7.4 shows the wave properties as ω varies for fixed η. Consider how the wave properties vary with η for $\beta = 1$ and fixed $\omega/(\nu_e c_s^2/c^2)$. Plot the normalized phase velocity and damping length for $0.01 \leq \eta \leq 10$ and discuss the results.

Homework 7.4

We did not explore the angular variation in the contributions to (7.34). One might imagine that the largest contributions could come at grazing angles, where μ is very small and the optical depth along a line of sight becomes large. The model used here would be less realistic if most of the emission came at grazing angles, because real systems will have layers that are not truly planar and certainly are not infinite in extent. Use a computational mathematics program to derive (7.34). Then modify the calculation in order to explore how large the contribution is from such grazing angles. Conclude whether or not the results above might be reasonable estimates for real layers.

Homework 7.5

It is curious that (7.39) and (7.41) do not depend on β, so that these waves seem not to care whether the system is fully ionized. Beginning with (7.37), derive (7.41) and discuss why there is no β dependence.

Homework 7.6

Beginning with $\rho(\partial\epsilon/\partial t) = \nabla \cdot (\kappa_{rad}\nabla T)$, derive (7.51).

Homework 7.7

Work through the constant-flux model, providing all the missing mathematical steps. Then plot the positions vs. time of the radiation wave and of a disturbance (in the radiation-heated material) moving at Mach 1 or Mach 10. Discuss the results.

Homework 7.8

Show that (7.74) is a solution to (7.73). Clearly annotated work with a computational mathematics program is preferred.

Homework 7.9

Consider a gold container shaped so that a planar approximation is reasonable, having planar walls spaced 1 mm apart in vacuum. Assume $\rho = 20\,\text{g/cm}^3$ and treat $c_V = 10^{12}$ ergs/(g eV) as constant. Use other parameters from Ch. 6 as appropriate. Suppose 100 kJ/cm^2 is the initial energy content of the vacuum between the walls and that the initial wall temperature is negligible. Approximate the heat front in the walls as a square wave. From zero to 10 ns, find the position of the heat front and the temperature of the surface as a function of time. Plot the ratio of the energy content of the walls to the energy content of the vacuum. Discuss the result.

Homework 7.10

Develop the equivalent of (7.76) for a spherically symmetric system.

Homework 7.11

Demonstrate this point explicitly by considering a system having a planar flow of material within a cylinder of some diameter and of finite length yet losing radiation both radially and axially, and integrating over the cylinder.

Homework 7.12

Derive (7.82).

Homework 7.13

Working with the Planck description of blackbody radiation, find and plot the fraction of photons that are ionizing as a function of temperature. You will need a computational mathematics program to generate the plot.

Homework 7.14

Determine whether (7.91) admits a self-similar solution, assuming a diffusive of F_R

Homework 7.15

Solve (7.94) numerically, for several relevant values of n. Comment on the results.

Homework 7.16

Evaluate the net radiation flux $(F_\mathrm{R} - F_o)$ for an optically thin precursor using a calculation similar to that done in (7.101) and (7.105).

Homework 7.17

Assuming that the upstream radiation flux at the shock is $2\sigma T_\mathrm{f}^4$, the intensity is isotropic, and the absorption and emission from the upstream medium contribute negligibly to J_R, find the steady-state temperature of the upstream medium.

Homework 7.18

Beginning with (7.80)–(7.82), derive the final inverse compression (7.115) under the assumptions of the present section.

Homework 7.19

Consider a truly radiation-dominated case, so p can be neglected in (7.124) and (7.125). Solve these equations for p_{R} and ρ. Find the dependence of the post-shock T on the shock velocity , and compare it to the dependence of a non-radiative shock.

Homework 7.20

Express p and p_{R} as reasonable functions of T and solve (7.124) and (7.125) to find T and ρ in the post shock state. This may be a numerical solution, for which you should make reasonable choices about the parameters and show a few cases. Provide at least one graph based on these equations as part of the analysis.

Homework 8.1

Derive (8.3) from Maxwell's equations.

Homework 8.2

Derive an equation for the conservation of charge from (8.3).

Homework 8.3

Using the equation of motion for the electron fluid in the fields of an electromagnetic wave in a plasma of constant density, determine the time-averaged distribution of energy among the electric field, the magnetic field, and the kinetic energy of the electrons. Discuss how this varies with density.

Homework 8.4

Derive (8.20).

Homework 8.5

Derive (8.22). Calculate the energy density of the laser light wave and show how this is related to the source term on the right-hand side.

Homework 8.6

Develop an energy equation for the electron fluid including a Spitzer–Harm heat flux, and show that it is a diffusion equation.

Homework 8.7

Determine the range of electron velocities that contribute significantly to the heat flux, by plotting the first-order contribution to the argument of the heat-flux integral (8.28).

Homework 8.8

Find the approximate expression for ϵ_R to second order in the quantity m_a/m_o. Plot the corresponding rocket efficiency and the value of (8.49). Discuss the comparison.

Homework 8.9

By analyzing the isothermal rarefaction, derive the ratio of the energy required to sustain the rarefaction to the energy injected into the rarefaction at the heat front.

Homework 8.10

Evaluate the ablation pressure (p_1) for the expansion heat front case, assuming the ablator is Be with a density ρ_o of 1.8 g/cm^3, as a function of radiation temperature from 100 eV to 300 eV. Compare the result with the value given by (8.58).

Homework 8.11

Assume that a hohlraum of 1 mm radius is heated for 1 ns at a temperature of 200 eV. Estimate the pressure produced at the center of the hohlraum when the plasma expanding from the gold walls reaches the axis. (Note: this is not an application of (8.67). Instead, you will need to think about the rarefaction produced during the heating pulse.)

Homework 8.12

While one can vary the properties of the Z-pinch load from one experiment to the next, one can modify the pulsed-power device itself on a somewhat longer timescale. Such devices are typically characterized by the number of Volt-Seconds they can produce, and operate so that $V\tau$ = constant. First, consider and then explain why Volt-Seconds is a reasonable way to characterize a pulsed-power device. Second, using the scaling relations developed in Sect. 8.3.1, discuss how to optimize the stagnation power for a device with $V\tau$ = constant.

Homework 8.13

An alternative way to think about what could be done with an imploding radiative shock is to imagine that one can drive a converging shock in an optically thin system. Assuming that such a shock reaches steady state, plot the radiation flux and its characteristic temperature against shock velocity for densities of 0.01 and 0.1 g/cm^3. Comment on the comparison with the above calculation.

Homework 8.14

Revisit the derivation at the beginning of Sect. 8.3. Consider two infinitely wide, plane parallel conductors carrying opposing currents. Find the force per unit area between them and express it in terms of the magnetic field magnitude. Discuss how the force per unit area compares to the energy density of the magnetic field.

Homework 9.1

Plot the burn fraction versus ρr. Discuss the impact of the assumptions made in deriving the burn fraction on this curve, and on the size of a system designed to produce a certain quantity of fusion energy.

Homework 9.2

Carry out the evaluation just described. For deuterium at a density of 0.1 g/cm^3, plot the pressure as a function of temperature for deuterium treated as bosons and for deuterium treated as a classical gas. Discuss the comparison.

Homework 9.3

Derive the classical relation between entropy and pressure (normalized by the Fermi pressure of the electrons).

Homework 9.4

Plot the minimum required implosion velocity , for $\rho r = 3$ g/cm^2, versus final fuel density. Discuss the result.

Homework 9.5

Derive (9.26). Why do we need to express this result using a 1/3 power?

Homework 9.6

Suppose that one could apply a pressure p for a time t, using some energy source. With this source, we could accelerate some amount of mass per unit area, $\rho_o \Delta r$, to $v_{\mathrm{imp}} = 300$ km/s. Define a fusion capsule using the reflected pressure due to sunlight for 12 h as the pressure source. Approximate sunlight as light with a wavelength of 580 nm and an irradiance of 1 $\mathrm{kW/m^2}$. How long would such a capsule take to implode?

Homework 9.7

Derive the spectrally averaged absorption coefficient for bremsstrahlung in DT. Check your value against the value found in the NRL plasma formulary.

Homework 9.8

Evaluate the appropriate integral of the radiative transfer equation over solid angle to obtain F_{R} from a spherical volume of DT. Find the value of the characteristic distance. Compare your result to the result in (9.31), which assumes that the integral over solid angle of the distance across the fuel gives πR_{h}. Extra credit: generalize this calculation to include arbitrary optical depth and discuss the results.

Homework 9.9

The Lawson criterion is generally written as $n\tau > 10^{14}$ $\mathrm{s/cm^3}$, with density n and confinement time τ. Find a way to relate this to (9.15) and comment on the comparison.

Homework 9.10

One choice in a central hot spot design is how much to increase the pressure above the minimum value of 13.5 Gbars. Increasing the pressure decreases the size of the hot spot but increases the energy required to create this pressure. Keeping the constraints on density and ρr found above, consider the effects of scaling the pressure in the hot spot.

Homework 9.11

Evaluate the amount of RT growth for the sunlight-driven fusion system of the problem 9.6.

Homework 10.1

Show that the Euler equations are in fact invariant under the transformations just described.

Homework 10.2

Design a diverging experiment to address the coupling of two structured, unstable interfaces that are affected by a blast wave. Beyond the basic requirements for hydrodynamic scaling , identify other specific parameters that are important to the dynamics. (Hint: review blast-wave propagation and shock stability as part of your work.)

Homework 10.3

Determine why t_{cc} as just defined is the relevant timescale for the crushing of the cloud.

Homework 10.4

Suppose that an astrophysical blast wave of interest is produced by a supernova explosion that is a known distance R from a clump of some radius r_{cl}. Determine the properties of an experimental blast wave and the duration of the experiment that would be required to model the shock-clump interaction in this system.

Homework 10.5

Magnetized jets must have a ratio of plasma pressure to magnetic field pressure (usually called β in plasma physics) no larger than about 1. For a low-Z plasma with a density of 0.1 g/cm^3 and a temperature of 10 eV, determine how large a magnetic field would be required to satisfy this constraint. How does this compare with the magnetic field of order 1 MGauss that is typically produced in laser-plasma interactions and that might be produced by very clever field-compression experiments?

Homework 10.6

An approach that has been used to form hydrodynamic jets is to create an adiabatic rarefaction by allowing a shock wave to emerge from a material into an evacuated tube and then to emerge from this tube into an "ambient medium", at a lower density. Using the simple scaling results from this book, develop a design for a similar experiment to produce a radiative jet.

Homework 11.1

Design a pulse stretcher. Suppose you have a laser beam with an 800 nm central wavelength and a bandwidth of 20 nm (corresponding to a 50 fs laser pulse). Use two identical gratings, recalling that for the first diffracted order the scattered wavelength λ is given by $\lambda = d(\sin\alpha + \sin\beta)$, where d is the line spacing on the grating and α and β are angles of incidence and reflection relative to the grating normal. Use two identical lenses, recalling that the object distance, o, image distance, i, and focal length f are related by $o^{-1} + i^{-1} = f^{-1}$. Note that the initial grating must be less than one focal length from the lens to obtain stretching.

Homework 11.2

Assuming that the electron motion is due to a plane wave with a single frequency and that the electron movement is small compared to the wavelength of the light wave, solve the above equations to find the electron trajectory. Determine how it changes as the electron velocity increases (while remaining $\ll c$).

Homework 11.3

Prove that these definitions (Eqs. 11.15 and 11.16) are equivalent.

Homework 11.4

Solve (11.25) for a range of values of the initial phase (i.e., change π to various other values, for fixed $a_o = 100$ and $\delta(0) = 0.01$. Comment on the variations in the behavior.

Homework 11.5

Find the time required to accelerate the electron to ~ 30 GeV in the example just given.

Homework 11.6

Suppose one has a laser beam that can be focused to 10^{20} W/cm^2 in a 10 μm diameter spot. Would one obtain higher-energy electrons from tunnel ionization (as in Sect. 11.2) or from using the laser for wakefield acceleration?

Homework 11.7

Solve for the potential of a spherical cloud of ions having uniform density, and for the energy distribution function of the ions produced by a Coulomb explosion of this cloud.

Homework 11.8

Derive the relativistic version of this theory and find the relativistically correct revision to (11.75).

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