CH EN 3453 – Heat Transfer

Blackbody Radiation

Sections 12.3 to 12.6

Reminders…

- Homework #10 due Friday
  - Help session 4:30 Wednesday in MEB 3235
- Final draft report due Friday
  - Email to Prof. Whitty in Microsoft Word format
  - Name the file “Draft - Firstname Lastname.docx”
    - Can also be in .doc format
  - Write “CH EN 3453 DRAFT REPORT” in the subject line
  - Send by 4:00 PM Friday
- Midterm #2 can be picked up in ChE office

Blackbody

- Hypothetical perfect radiative surface
- Absorbs all incident radiation, regardless of wavelength and direction
- Emits maximum theoretical energy
- Diffuse emitter – Radiation emitted evenly in all directions

Review

- Solid angle

$$\omega = \frac{A_n \cos\theta}{r^2}$$

- Spectral intensity

$$I = \frac{E}{\pi}$$

- Radiation energy rate

$$q = \frac{I A_1 A_n \cos\theta_1 \cos\theta_2}{r^2}$$

The Planck Distribution

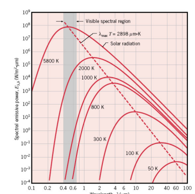
- Emissive power of a blackbody depends on *temperature* and *wavelength*
- Planck figured out this relation

$$E_{\lambda,b}(\lambda,T) = \pi I_{\lambda,b}(\lambda,T) = \frac{C_1}{\lambda^5\left[exp(C_2/\lambda T)-1\right]}$$

First radiation constant: $C_1 = 3.742 x 10^8 \, W \cdot \mu m^4 / m^2$

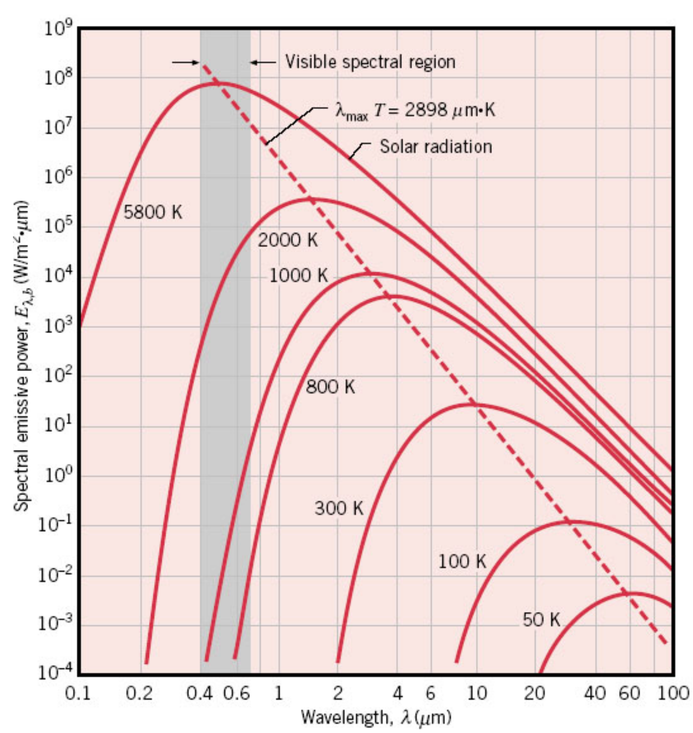
Second radiation constant: $C_2 = 1.439 x 10^4 \, \mu m \cdot K$

- Plot of *E* vs. λ looks like this:



NOTES:

- Total power increases with temperature
- At any given wavelength the magnitude of emitted radiation increases with temperature
- Wavelength of radiation decreases with temperature
- Sun is approximated by blackbody at 5800 K
- At T < 800 K, most radiation in infrared



Wien's Displacement Law

- For a given temperature, spectral emission goes through a maximum at a given wavelength.
- Wien figured this one out:

$$\lambda_{max}T = C_3 = 2898\ \mu\text{m}\cdot\text{K}$$

- This maximum is indicated by the dashed line in Figure 12.12

Stefan-Boltzmann Law

- If one were to integrate any of the curves shown in Figure 12.12 over the entire range of wavelengths, one would get the *total emissive power* for a blackbody:

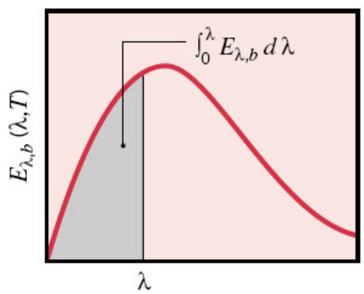
$$E_b = \int_0^\infty \frac{C_1}{\lambda^5\left[\exp\left(C_2 / \lambda T\right) - 1\right]} d\lambda$$
$$= \sigma T^4$$

- The *Stefan-Boltzmann constant* σ is:

$$\sigma = 5.670 \times 10^{-8}\ \text{W/m}^2\cdot\text{K}^4$$

Band Emission

- Amount of total emitted radiation depends on range of wavelengths of emission
- Effective emissivity determined by integrating over wavelengths
- Table 12.1, column "F" provides fraction of total integrated area to a given wavelength



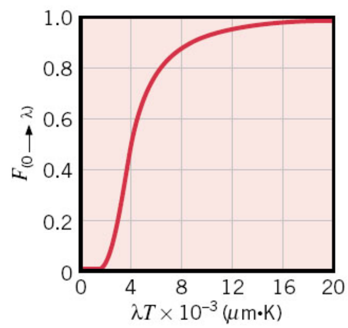


TABLE 12.1 Blackbody Radiation Functions

λT (μm · K)	$F_{(0\to\lambda)}$	$I_{\lambda,b}(\lambda,T)/\sigma T^5$ (μm · K · sr)$^{-1}$	$\frac{I_{\lambda,b}(\lambda,T)}{I_{\lambda,b}(\lambda_{max},T)}$
200	0.000000	0.375034×10^{-27}	0.000000
400	0.000000	0.490335×10^{-13}	0.000000
600	0.000000	0.104046×10^{-8}	0.000014
800	0.000016	0.991126×10^{-7}	0.001372
1,000	0.000321	0.118505×10^{-5}	0.016406
1,200	0.002134	0.523927×10^{-5}	0.072534
1,400	0.007790	0.134411×10^{-4}	0.186082
1,600	0.019718	0.249130	0.344904
1,800	0.039341	0.375568	0.519949
2,000	0.066728	0.493432	0.683123
2,200	0.100888	0.589649×10^{-4}	0.816329
2,400	0.140256	0.658866	0.912155
2,600	0.183120	0.701292	0.970891
2,800	0.227897	0.720239	0.997123
2,898	0.250108	0.722318×10^{-4}	1.000000
3,000	0.273232	0.720254×10^{-4}	0.997143
3,200	0.318102	0.705974	0.977373
3,400	0.361735	0.681544	0.943551
3,600	0.403607	0.650396	0.900429
3,800	0.443382	0.615225×10^{-4}	0.851737
4,000	0.480877	0.578064	0.800291
4,200	0.516014	0.540394	0.748139
4,400	0.548796	0.503253	0.696720
4,600	0.579280	0.467343	0.647004
4,800	0.607559	0.433109	0.599610
5,000	0.633747	0.400813	0.554898
5,200	0.658970	0.370580×10^{-4}	0.513043
5,400	0.680360	0.342445	0.474092
5,600	0.701046	0.316376	0.438002
5,800	0.720158	0.292301	0.404671
6,000	0.737818	0.270121	0.373965
6,200	0.754140	0.249723×10^{-4}	0.345724
6,400	0.769234	0.230985	0.319783
6,600	0.783199	0.213786	0.295973
6,800	0.796129	0.198008	0.274128
7,000	0.808109	0.183534	0.254090
7,200	0.819217	0.170256×10^{-4}	0.235708
7,400	0.829527	0.158073	0.218842
7,600	0.839102	0.146891	0.203360
7,800	0.848005	0.136621	0.189143
8,000	0.856288	0.127185	0.176079
8,500	0.874608	0.106772×10^{-4}	0.147819
9,000	0.890029	0.901463×10^{-5}	0.124801
9,500	0.903085	0.765338	0.105956
10,000	0.914199	0.653279×10^{-5}	0.090442
10,500	0.923710	0.560522	0.077600
11,000	0.931890	0.483321	0.066913
11,500	0.939959	0.418725	0.057970
12,000	0.945098	0.364394×10^{-5}	0.050448
13,000	0.955139	0.279457	0.038689
14,000	0.962898	0.217641	0.030131
15,000	0.969981	0.171866×10^{-5}	0.023794
16,000	0.973814	0.137429	0.019026
18,000	0.980860	0.908240×10^{-6}	0.012574
20,000	0.985602	0.623310	0.008629
25,000	0.992215	0.276474	0.003828
30,000	0.995340	0.140469×10^{-6}	0.001945
40,000	0.997967	0.473891×10^{-7}	0.000656
50,000	0.998953	0.201605	0.000279
75,000	0.999713	0.418597×10^{-8}	0.000058
100,000	0.999905	0.135752	0.000019

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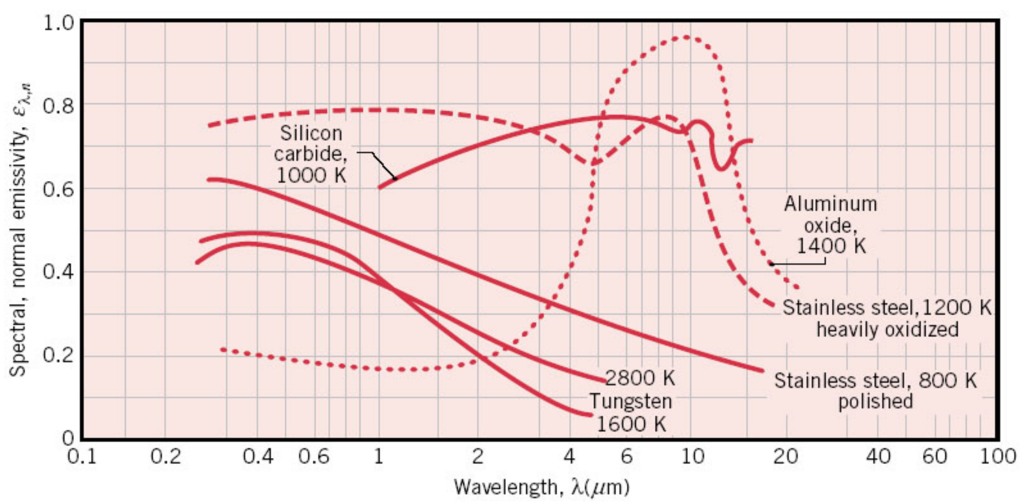
3,000	0.273232	0.720254×10^{-4}	0.997143
3,200	0.318102	0.705974	0.977373

Spectral Emissivity



Example: 12.29

- The spectral, hemispherical emissivity of tungsten may be approximated by the distribution given below. What is the total hemispherical emissivity when the filament show below is 2900 K?