PHY392 Midterm Exam
26 February 2014
Duration: 50 minutes
Aids allowed: a non-programmable calculator
Possibly useful constants and equations are given at the end

1. (30 marks)

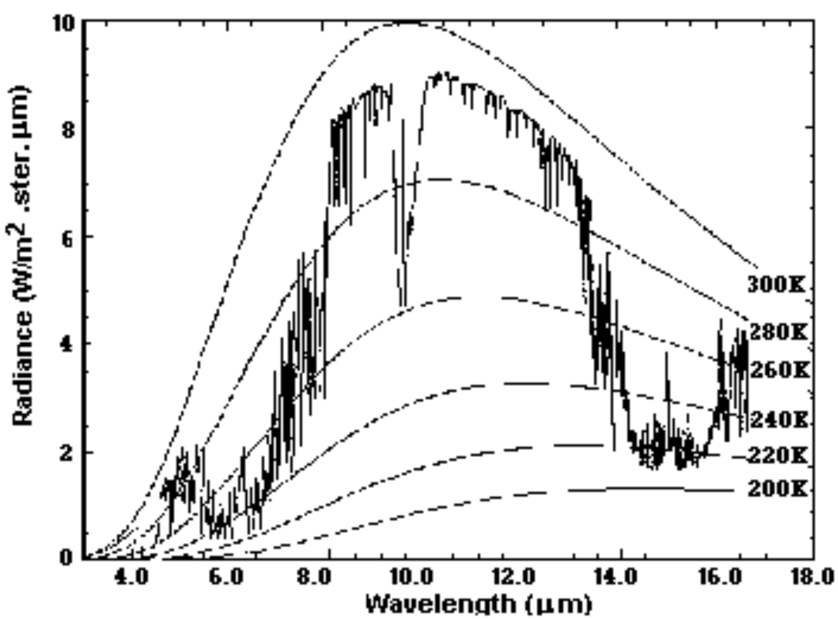
a) Consider two houses which are identical, except that one is better insulated than the other. They have identical furnaces, which are producing heat at the same rate. From the outside, assuming equilibrium, can you tell which house is better insulated? Why or why not? ***(5 marks)***

b) In a conditionally unstable atmosphere ($\Gamma_s < -dT_e/dz < \Gamma_d$), where T_e is the environmental temperature, is a cloudy air parcel stable or unstable with respect to *sinking* motions? Explain. ***(5 marks)***

The figure below shows the emission spectrum of the atmosphere as measured by the GOES satellite over a region of the surface of Earth.

c) Identify the features seen between 9-10 μm and 14-16 μm. ***(4 marks)***

d) Assuming a uniform lapse rate of 6.5 K/km, estimate the altitude from which the radiation between 14-16 μm shown in the figure is emerging. ***(6 marks)***



At present, the emission temperature of Earth, T_e, is 255 K and its albedo, A_p, is 0.30. How would Earth's emission temperature change if:

e) the albedo was reduced to 0.10 (and all other parameters were held fixed)? ***(6 marks)***

f) the infrared absorptivity of the atmosphere was doubled, but the albedo remained fixed at 0.30? ***(4 marks)***

2. (20 marks)
Consider a two-layer model for Earth's atmosphere that consists of

- a "main" atmospheric layer of temperature T_{main} that is transparent to solar radiation and absorbs a fraction $\varepsilon = 0.77$ of terrestrial radiation;
- a "thin" atmospheric layer, with temperature T_{thin}, above this main layer that is transparent to solar radiation and absorbs a small fraction $\varepsilon' << 1$ of terrestrial radiation. This layer is often called the "planetary skin."

Calculate the temperature T_{thin}. This temperature represents the coldest temperature achievable in Earth's atmosphere in the absence of dynamical effects or absorption of solar radiation by gas molecules. Explain why briefly.

Maximum exam marks = 50 points

PHY392
USEFUL CONSTANTS AND FORMULAS

Constants

Gravitational constant	G	6.67×10^{-11} N m^2 kg^{-2}
Universal gas constant	R^*	8.3143 J K^{-1} mole^{-1}
Speed of light in vacuum	c	2.998×10^8 m s^{-1}
Planck's constant	h	6.626×10^{-34} J s
Boltzmann's constant	k	1.381×10^{-23} J K^{-1}
Avogadro's number	N_A	6.02×10^{23} particles/mole
Stefan-Boltzmann constant	σ	5.67×10^{-8} W m^{-2} K^{-4}
First radiation constant	c_1	1.191×10^{-16} W m^2 sr^{-1}
Second radiation constant	c_2	1.439×10^{-2} m K

Planetary and Sun

Mean surface pressure on Earth	p_s	1.013×10^5 Pa = 1013 mbar
Mean surface temperature on Earth	T_s	288 K
Earth's emission temperature	T_e	255 K
Mean surface density on Earth	ρ_s	1.235 kg m^{-3}
Earth's rotation rate	Ω	7.27×10^{-5} s^{-1}
Earth's mean radius	a	6.38×10^6 m
Mean Earth-Sun distance	d_{Earth}	1.5×10^{11} m
Solar constant	L_0	1367 W m^{-2}
Mean Earth albedo	A_p	0.30

Properties of Dry Air

Standard pressure	p_o	1013.25 hPa
Standard temperature	T_o	273.15 K
Specific heat at constant pressure	c_p	1005 J kg^{-1} K^{-1}
Specific heat at constant volume	c_v	718 J kg^{-1} K^{-1}
Air density at 273 K, 1013 hPa	ρ_0	1.293 kg m^{-3}
Gas constant for dry air	R or R_d	287 J kg^{-1} K^{-1}
Gas constant for water vapour	R_v	461.39 J kg^{-1} K^{-1}
Mean molecular weight of dry air	M_a	28.97 g/mole

PHY392
POSSIBLY USEFUL EQUATIONS

$$p = \rho RT = n_0 kT \qquad pV = NkT \qquad R = \frac{R^*}{M_a}$$

$$\text{volumetric mixing ratio } (VMR_i) = \frac{N_i}{\sum_i N_i} = \frac{n_i}{\sum_i n_i} = \frac{p_i}{\sum_i p_i}$$

$$\text{mass mixing ratio } (MMR_i) = \frac{m_i}{\sum_i m_i} = \frac{\rho_i}{\sum_i \rho_i} = \left(\frac{M_i}{\bar{M}}\right) VMR_i$$

$$\frac{dP}{dz} = -\rho g \qquad p(z) = p_0\ e^{-\frac{z}{H}} \qquad H = \frac{R^* T}{M_a g} = \frac{RT}{g}$$

$$\theta = T\left(\frac{p_o}{p}\right)^{R/c_p} \qquad c_p = c_v + R \qquad \Gamma_d = \frac{g}{c_p}$$

$$\frac{d\ln T}{d\ln P} = \frac{R}{c_p} \qquad dS = c_p\, d\ln\theta \qquad T(p) = \frac{T_0}{1 - \frac{RT_0}{L}\ln\left(\frac{p}{p_{sat}(T_0)}\right)}$$

$$d\Omega = d\left(\frac{A}{r^2}\right) = \sin\theta\ d\theta\ d\varphi \qquad \lambda_{\max} = \frac{2897.9}{\mathrm{T}} \qquad F_\lambda = \pi B_\lambda$$

$$B_\lambda(T) = \frac{2hc^2\lambda^{-5}}{\exp\left(\frac{hc}{\lambda kT}\right) - 1} = \frac{c_1\lambda^{-5}}{\exp\left(\frac{c_2}{\lambda T}\right) - 1} \qquad B_\nu(T) = \frac{2h\nu^3 c^{-2}}{\exp\left(\frac{h\nu}{kT}\right) - 1}$$

$$T_s = (N+1)^{1/4} T_e \qquad T_s = \left(\frac{2}{2-\varepsilon}\right)^{1/4} T_e \qquad T_a = \left(\frac{1}{2-\varepsilon}\right)^{1/4} T_e$$