1. Find the rms Johnson noise voltage, $< V_{ab} >_{rms}$ for the two resistors connected in series above ($B = 10 \text{ kHz}$ and $T = 100 \text{ K}$).

2. (a) A resistor at temperature $T$ can be represented as an ideal noiseless resistor in series with a noise voltage source $< V_n >_{rms} = \sqrt{4kTRB}$. The resistor can also be represented as a Norton equivalent consisting of the noiseless resistor in parallel with a noise current source $< I_n >_{rms}$. Equate the open circuit voltages of the two models to derive an expression for $< I_n >_{rms}$.

(b) Use this result to find the total open circuit Johnson noise voltage $< V_{ab} >_{rms}$ for the parallel resistors in the figure below assuming the following values: $R_1 = 10 \text{ k}\Omega$, $R_2 = 20 \text{ k}\Omega$, $B = 10 \text{ kHz}$ and $T = 100 \text{ K}$.

(c) Show this is what you expect for the noise due to the combined resistance.
3. The figure above shows a BJT in a common emitter circuit biased such that $I_C = 1.0$ mA. $I_C$ displays full shot noise (electrons can be considered independent of each other in passing from the emitter across the base into the collector). There are other noise sources in the circuit but we will only consider $v_n$, the $R_C$ Johnson noise, and $i_n$, the $I_C$ shot noise. Recall that for shot noise, $<I_n>_{\text{rms}} = (2qI_{DC}B)^{\frac{1}{2}}$ where $q = 1.60 \times 10^{-19}$ C. Assume $T = 300$ K.

(a) Find $v_n$, the rms voltage due to the resistor Johnson noise (for the 20 kHz bandwidth).

(b) i. Find $i_n$, the rms shot noise current (for the 20 kHz bandwidth)

ii. Find the rms noise voltage at the output due to this noise current

(c) Find the total noise voltage at the output within the 20 kHz bandwidth. Which noise source is dominant?

4. A non-inverting amplifier (see figure below) is made from a low-noise AD797 op-amp. The feedback resistance values are the same as in our circuit ($R_1 = 10 \, \Omega$, $R_2 = 100 \, \Omega$). The op-amp has a voltage noise spectral density of $e_n = 0.9 \, \text{nV/}\sqrt{\text{Hz}}$ (“adjusted” value for differential configuration) and current noise spectral density of $i_n = 2.0 \, \text{pA/}\sqrt{\text{Hz}}$. Find the total noise voltage spectral density $e_t$ (referred to the amplifier non-inverting input) when each of the following resistors is connected:

(a) 100 $\Omega$

(b) 1000 $\Omega$

(c) 10000 $\Omega$.

In each case, find the fraction of the total noise contributed by the resistor Johnson noise.

Hint: See Sec. 7.17 in Horowitz and Hill, *The Art of Electronics, 2nd. Ed.*, from which the figure was taken.