A310G Examination #2

1. Energy associated with matter is generally <u>kinetic energy</u>, *i.e.*, energy associated with motion of the matter or of its constituent particles. That is, KE = $mv^2/2$, and the temperature of an ensemble of particle is proportional to the average kinetic energy of the particles.

Energy associated with <u>radiation</u> is not associated with mass in the usual sense but with the energy carried by massless photons each with energy $h\nu$, or in an electromagnetic wave of amplitude **B**, in which case the energy is proportional to B^2. Whether viewed as electromagnetic waves or as quanta, radiative energy (and momentum) propagates at the speed of light c.

<u>Potential energy</u> is "stored energy" and often associated with matter in the presence of a field of force which acts upon its mass (gravity) or its charge (electric and magnetic forces, which include chemical binding forces). An atom or molecule in an excited state represents potential energy, for example. Indeed, energy stored in any system can be regarded as potential energy if that energy is capable of being extracted to do work.

In any case, radiative energy can be transformed into matter's kinetic or potential energy by the process of absorption. The inverse processes of spontaneous emission and "stimulated emission" (and their free-free variants) can convert that energy back into the radiative form.

2. The three most basic forms or energy transport are (1) radiative, where the energy is transported by electromagnetic radiation, (2) convective, which involves large-scale motions of "warm" matter to cooler regions of lower energy density, and (3) conductive, which involves small scale motions of matter. Wavelike (oscillatory) motions of matter (*e.g.*, sound waves) or of charged matter (*e.g.*, AC electrical currents) can be thought of as fitting onto one of the last two categories, depending on the associated (wave-) length scale.

A fourth distinct mechanism, which has not been directly observed but whose occurrence has been indirectly inferred, is the transport of energy *via* gravitational waves.

3. The wavelike nature of light (electromagnetic radiation) is made manifest by the phenomena of diffraction and interference, neither of which (especially the latter) can be understood in terms of a classical particle view of light. Polarization also falls into this category. On the other hand, certain radiative phenomena (*e.g.*, the spectrum of black body radiation) can best be explained by the quantization of radiation (Planck, 1901) and the photoelectric effect can only be explained with a quantum (= photon = corpuscle) interpretation of light (Einstein, 1905). It is then necessary to ascribe the additional property of "spin" to these quanta in order to understand polarization.

The dichotomy or contradiction can only be resolved by realizing that light is not a wave or a particle but both. In practice one can measure either the uniquely wavelike properties of light or the photon properties of light - but cannot, in principle, do both simultaneously. In other words, the "contradiction" is not observable! (If a tree falls in the forest ...) It is this curiosity that led, in large part, to the foundation of quantum mechanics: even "matter" exhibits wavelike properties at some scales.

4. The Special Theory of Relativity (and its seemingly rather bizarre predictions) follows almost inexorably from the Principle of Relativity (that the Laws of Nature should be observed to be the same at all places and times) plus the observation of the "constancy" of the speed of light. The driving motivation for STR was basically the Michelson-Morely experiment which seemed to establish the nonexistence of the "luminiferous ether" and the constancy of the speed of light. As it happens, Maxwell's Electromagnetism plus the Principle of Relativity also implies the constancy of the speed of light; Maxwell's equations were based upon observation as well. In any case, Newtonian Mechanics is based upon the presumed absoluteness of time and the consequent Galilean transformations but it is inconsistent with either Maxwell's Equations or the observed constancy of the light speed.

Some of the "revolutionary" predictions of Special Relativity were:

• Time (or, rather, the perceive rate of its passage) is no longer an absolute but depends upon the relative velocity of the observer and the frame in which the timed events occur.

• The perceived length of a real object depends upon its velocity relative to the observer's frame; an object will appear shortened along the direction of their motion. (This is the Fitzgerald-Lorentz contraction.)

• The perceived (measured) inertial mass of an object (*i.e.*, its ability to resist acceleration in response to an applied force) increases without limit as the relative speed of the object approaches the speed of light.

• More-or-less as a consequence of the first item, radiation form a moving source will exhibit a *transverse* Doppler effect even in the absence of any radial component to the source's motion. Such an effect is absent from Newtonian mechanics.

• The equivalence of mass and energy: A mass at rest possesses an intrinsic energy even in the absence of an energy associated with its motion. It should be, at least in principle, possible to convert mass to energy - and *vice versa*. It is, in fact, possible in practice.

All of the above predictions (as well as the postulates of Special Relativity, the Principal of Relativity and the constancy of the speed of light) have been repeatedly and successfully tested to increasingly high levels of precision and accuracy. The corresponding predictions of Newtonian mechanics do not meet these tests. However, in the realm of velocities, v, where $v \ll c$, Newtonian mechanics generally provides a "good approximations" to reality.

Note that one of the implicit assumptions of STR (and of Newtonian Mechanics) is that we live in a "flat" spacetime. That assumption leads to some problems, ambiguities, and outright contradictions when one considers motions in the presence of gravity. These were the problems that led to Einstein's formulation of the General Theory of Relativity and the realization that spacetime can be curved.