Electrical Fundamentals

Set 18: Circuits and Safety

18.1		The active or live wire is the conductor at the high potential, nominally $V_{rms} = 240$ V The neutral wire is at a potential very close to zero relative to the active wire. The earth wire is a safety feature which is permanently connected to ground and therefore at a potential of 0 V.
18.2		Even small potential differences, such as 12 V car batteries, can deliver huge currents (up to 100 A) which can be fatal. However, a school laboratory Van der Graaf generator can build up a potential of thousands of volts, but if a student touches it, thereby establishing an equivalent potential difference, it may provide a slight, but non-fatal shock. Generally, the resistance of the load (combined with the internal resistance of the supply) will determine the current, not the potential difference itself.
18.3		$I_{globe} = \frac{P}{V} = \frac{40\ W}{240\ V} = 0.166\ A$ so the number of globes possible = $\frac{15\ A}{0.166\ A} = 90$ globes In practice, the circuit breaker would probably not cut out at exactly 15 A, so you could probably run a few more globes than this from the lighting circuit.
18.4		$I_{min} = \frac{V}{R} = \frac{12\ V}{2.4\ \Omega} = 5.0\ A$
18.5	(a)	In the event of a short circuit, a huge current surge would generate significant heat energy which would melt / damage the guilty conductor and cause a break in the circuit, thereby stopping the current flow before an electric shock could occur.
	(b)	'Time-current' is a combination of the magnitude of the current flow and the time for which it acts. Direct current does produce similar biological effects to that of alternating current, however the least DC time-current that will cause biological problems is greater than the corresponding AC time-current.
	(c)	The Earth wire is an essential safety feature which allows the safe operation of appliances with metal casings. However, if the appliance was doubly insulated, then in the event that a casing should become 'live' due to a fault, then the higher resistance of the protective layer would result in a much lower current flowing to the outer shell.
18.6	(a)	$I_{heater} = \frac{P}{V} = \frac{1200\ W}{240\ V} = 5.0\ A$
	(b)	The 15 A circuit-breaker should not become an issue until the current drawn by the appliances is around 15 A. Since two heaters would only draw 10.0 A in total, then they would operate fine.
18.7		Total power consumption = 1000W + 2400W + 2000W = 5400 W The resulting current flow, $I_{total} = \frac{P}{V} = \frac{5400\ W}{240\ V} = 22.5\ A$ This would obviously trip the 15 A circuit-breaker, so you should not use these three appliances.

18.8		The larger resistance wires can accommodate a bigger current flow and still function safely, therefore a fuse with a larger current rating should be installed.
18.9		All three safety features will ultimately break an electrical circuit and stop current flowing, although it may take anything from a fraction of a second to several seconds to do so. This may prevent a shock hazard in most cases, particularly in domestic situations, although they will not prevent all hazards.
18.10	(a)	$I_{globe} = \frac{P}{V} = \frac{100\text{ W}}{240\text{ V}} = 0.417\text{ A}$ so the number of globes possible = $\frac{10\text{ A}}{0.417\text{ A}} = 24$ globes
	(b)	Total power consumption = 1800W + 2400W = 4200 W The resulting current flow, $I = \frac{P}{V} = \frac{4200\text{ W}}{240\text{ V}} = 17.5\text{ A}$ This too great current would obviously 'blow' the 15 A fuse.
	(c)	The fuse in both cases protects the user of the appliances from an electrical shock hazard or an electrical burn, however it also protects the appliances themselves from permanent damage which could prove financially costly.
	(d)	Thick copper wire would have a very low resistance and therefore allow a much larger and potentially fatal current, to flow through it before 'blowing'.
	(e)	In the event of a short circuit, a huge current surge would generate significant heat energy which would melt / damage the guilty conductor and cause a break in the circuit, thereby stopping the current flow before an electric shock could occur. Hence, the risk of electrocution maybe prevented.
18.11		Power boards demand appliances be connected in parallel and they operate from a 240 V supply. $I_{heater} = \frac{V}{R} = \frac{240\text{ V}}{35\,\Omega} = 6.86\text{ A}$ $I_{lamp} = \frac{V}{R} = \frac{240\text{ V}}{110\,\Omega} = 2.18\text{ A}$ $I_{CD\ player} = \frac{V}{R} = \frac{240\text{ V}}{750\,\Omega} = 0.32\text{ A}$ $I_{cassette\ player} = \frac{V}{R} = \frac{240\text{ V}}{640\,\Omega} = 0.375\text{ A}$ $I_{amplifier} = \frac{V}{R} = \frac{240\text{ V}}{350\,\Omega} = 0.686\text{ A}$ The total current drawn form the power board, I_{total} = 10.42 A This exceeds the 10 A safety margin so Alec's circuit will not work.
18.12	(a)	$R = \frac{V}{I} = \frac{240\text{ V}}{0.04\text{ A}} = 6.0\text{ k}\Omega$
	(b)	$I_{neutral}$ = 1500mA – 40mA = 1460 mA (or 1.46 A)

18.13	(a)	$I_{griller} = \frac{P}{V} = \frac{1500\text{ W}}{240\text{ V}} = 6.25\text{ A}$
	(b)	$R_{fridge} = \frac{V}{I} = \frac{240\text{ V}}{10\text{ A}} = 24.0\,\Omega$
	(c)	I_{total} = 10A + 6.25A = 16.25 A, so the circuit breaker will be activated when the fridge starts up.
18.14	(a)	$I_{max} = \frac{V}{R_{min}} = \frac{3000\text{ V}}{50 \times 10^6\ \Omega} = 6 \times 10^{-5}$ A or 60 μA
	(b)	A typical torch bulb may be rated at 3 V, 500 mA when operating normally. This would suggest a resistance, $R = \frac{V}{I} = \frac{3\text{ V}}{0.5\text{ A}} = 6.0\,\Omega$. When competing with the 50 MΩ series safety resistor, its share of the voltage supply will be minimal: $I = \frac{V}{R} = \frac{3000\text{ V}}{(6\,\Omega + 50000006\,\Omega)} = 5.999 \times 10^{-5}$ A or 59.9 μA so $V_{torch} = I \times R_{torch} = 5.999 \times 10^{-5}\text{A} \times 6\ \Omega = 3.59 \times 10^{-4}$ V (about 360 μV)
	(c)	The 50 MΩ resistor acts like an internal resistance, such that even in the event of a short circuit when the external resistance could be very close to 0 Ω, the maximum current that can result is limited to 60 μA which should be non-fatal.
18.15	(a)	$I_{John} = \frac{V}{R} = \frac{240\text{ V}}{4400\,\Omega} = 5.45 \times 10^{-2}$ A or 54.5 mA
	(b)	Carmen is effectively joining John in parallel, so the combined resistance will now be less thereby drawing a bigger current. Although there are two separate current paths, John will effectively have both running through his heart - the original 54.5mA and now the extra current running along his arm span to Carmen.
	(c)	$I_{Carmen} = \frac{V}{R} = \frac{240\text{ V}}{(8000\,\Omega + 400\,\Omega)} = 2.86 \times 10^{-2}$ A or 28.6 mA
	(d)	Carmen should have isolated the power supply initially – turned off the electricity.
	(e)	The total current flowing = 54.5 mA + 28.6 mA = 83.1 mA, although potentially hazardous for John, it is not large enough to 'blow' the fuse in the power points circuit.