

Unit 1: Biosynthetic Pathways and Radio Tracing Techniques

Free notes at pharmacolearn.fyi

Phytochemistry, subject code MPG103T, is the third core theory subject of M.Pharm Pharmacognosy, Semester 1. It carries 4 credits and 60 hours of theory, taught at 4 hours per week, for 100 marks. Its scope, as the syllabus states it, is to learn knowledge of natural product drug discovery and to be able to isolate, identify and extract the phytoconstituents. This subject asks the chemical questions underneath pharmacognosy: how does the plant build its active constituents, how were they turned into medicines, how are they got out of the plant material and separated, and how is their identity and structure proved? Five units answer in order. Unit 1 covers biosynthetic pathways and radio tracing techniques, following the named alkaloids, glycosides, steroids, a coumarin and terpenoids from building blocks to finished constituent, with their importance in the herbal industries. Unit 2 covers drug discovery and development: the history of herbs as sources of drugs, lead selection and optimization through artemisinin and the andrographolides, the product discovery process and drug registration, and clinical studies with the phases of trials and protocol design. Unit 3 covers extraction and phytochemical studies: choice of method and solvent, successive and exhaustive extraction, microwave assisted extraction and the other modern methods, fractionation, and separation including preparative HPLC and flash column chromatography. Unit 4 covers phytochemical fingerprinting: HPTLC and LC-MS and GC-MS in the characterization of herbal extracts, and the general subject of structure elucidation. Unit 5 applies UV, IR, MS and NMR (^1H and ^{13}C) to nine named compounds: carvone, citral and menthol; luteolin and kaempferol; nicotine and caffeine; and glycyrrhizin. One discipline runs through the notes: a pathway is proved by labelled atoms, an extract is known by its fingerprint, and a structure is proved when independent spectra agree.

1.1 Primary and secondary metabolism: where phytoconstituents come from

Every phytoconstituent in this unit is a product of plant metabolism, and the first distinction is between primary and secondary metabolism. Primary metabolism is the chemistry every living plant cell runs to live and grow: photosynthesis, the interconversion of sugars, and the making of amino acids, nucleotides, fatty acids and the polymers built from them. Its products are universal, because the cell cannot live without them. Secondary metabolism branches off from it and makes the specialised compounds, the secondary metabolites, that give a species its chemical character: alkaloids, glycosides, terpenoids, steroids, flavonoids and the rest of the pharmacognosy catalogue. They serve the plant in its world, deterring herbivores and microbes, attracting pollinators and screening ultraviolet light, and they are distributed unevenly, in one family or species, one organ, one stage of growth. That unevenness is why they matter to pharmacy: a compound made by almost no other organism, with a strong effect on animal physiology, is a drug lead waiting to be noticed.

Biosynthesis is the step by step enzymatic building of these compounds inside the plant, and a pathway is the ordered sequence of intermediates and enzymes from a primary starting material to the finished metabolite. The pathways draw on a small set of shared building blocks: acetyl and malonyl coenzyme A; the aromatic amino acids phenylalanine, tyrosine and tryptophan; the five carbon isoprene units IPP and DMAPP; and amino acids such as ornithine and lysine used directly as skeletons. Four great routes organise the unit, and every named compound belongs to one of them or to a combination. The shikimate pathway supplies aromatic compounds: phenylpropanoids, coumarins, flavonoids and the aromatic halves of many alkaloids. The acetate malonate route supplies polyketide compounds, and the acetate mevalonate

route, with its plastid partner the MEP pathway, supplies the isoprene units behind all terpenoids and steroids. The amino acid pathways supply the alkaloids, whose nitrogen and much of whose skeleton come straight from an amino acid. The map below shows the four routes.

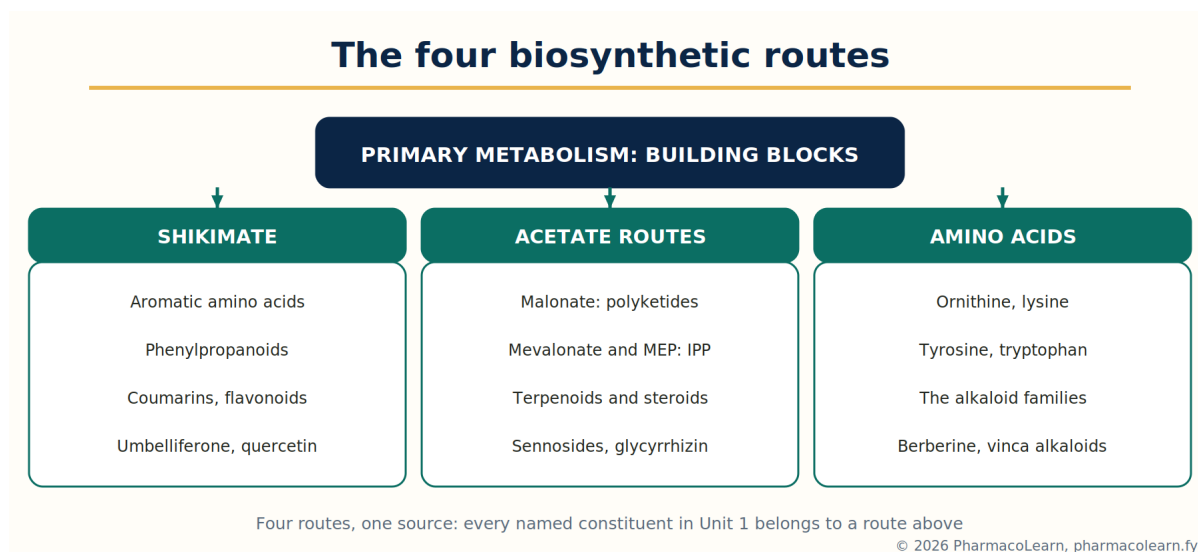


Figure: The four great biosynthetic routes of this unit. Primary metabolism supplies the building blocks; the named syllabus compounds are the end products of the routes shown.

Three working ideas recur in every pathway answer. First, the building block idea: a complex product is assembled from small units joined regularly, so its structure carries their pattern, the alternating oxygenation of a polyketide, the five carbon repeats of a terpenoid, the C6-C3 unit of a phenylpropanoid. Second, the intermediate idea: between building block and product stands a sequence of intermediates, each made by one enzyme, and the pathway is that list in order. Third, the evidence idea: a textbook pathway is a proved claim, and the proof, for most classical pathways, came from radio tracing, the subject of Section 1.5.

1.2 The shikimate pathway and the phenylpropanoids

The shikimate pathway is the plant route to aromatic compounds, named for shikimic acid, its best known intermediate, first isolated from the Japanese star anise (*Illicium*, shikimi in Japanese). It operates in plants and microorganisms and not in animals, which is why its products, the aromatic amino acids, are essential nutrients for animals. In outline, the pathway condenses phosphoenolpyruvate (from glycolysis) with erythrose 4-phosphate (from the pentose phosphate pathway) and proceeds through shikimic acid to chorismic acid, the branch point of aromatic biosynthesis, from which the plant makes phenylalanine, tyrosine and tryptophan.

For pharmacognosy the decisive branch is phenylalanine. Phenylalanine ammonia lyase removes ammonia from phenylalanine to give cinnamic acid, opening the phenylpropanoid pathway, the source of the C6-C3 family: hydroxycinnamic acids such as caffeic and ferulic acid, the coumarins (Section 1.12), the lignans, and, by joining a phenylpropanoid unit with acetate derived units, the flavonoids. Umbelliferone is a direct phenylpropanoid product, formed by hydroxylation and lactone ring closure of a cinnamic acid derivative. The flavonoids, quercetin among them, are mixed origin: their B ring and three carbon bridge come from phenylalanine, their A ring from three acetate malonate units, and examiners reward the student who can say which part came from which route. Tryptophan feeds the indole alkaloids (Sections 1.8 and 1.9) and tyrosine the isoquinoline alkaloids such as berberine, so the shikimate pathway stands behind much of the alkaloid list as well.

1.3 The acetate pathways: polyketides, mevalonate and the MEP route

Acetate, carried as acetyl coenzyme A and its carboxylated partner malonyl coenzyme A, is the second great building block system, and it works in two distinct ways that must not be confused. In the acetate malonate or polyketide mode, acetyl and malonyl units are joined head to tail into a growing chain, exactly as fatty acids are built, but the chain is then folded and cyclised, often with its oxygen atoms retained in a regular alternating pattern, to give aromatic and phenolic products: the A ring of the flavonoids, many anthraquinones including the sennosides of Section 1.10 in their ring system, and a wide range of phenolic compounds. The retained, regularly spaced oxygenation is the structural signature of a polyketide origin.

In the second mode, three acetate units are assembled into mevalonic acid, and mevalonate is converted, with loss of one carbon, into the five carbon units IPP and DMAPP. This acetate mevalonate pathway is the classical route to terpenoids and steroids. Plants also run a second route to the same units, the methylerythritol phosphate (MEP) pathway, also called the non mevalonate or DOXP pathway, building IPP and DMAPP from pyruvate and glyceraldehyde 3-phosphate in the plastids. The working rule is compartmentation: the cytosolic mevalonate pathway chiefly supplies sesquiterpenoids, triterpenoids and steroids, while the plastid MEP pathway chiefly supplies monoterpenoids, diterpenoids and carotenoids. The MEP route is the standing lesson that a pathway map is never finished: plastid terpenoids labelled in a pattern mevalonate could not explain, and following that anomaly revealed the second route.

Once IPP and DMAPP exist, terpenoid biosynthesis is an assembly line of chain lengthening and cyclisation. DMAPP and IPP join to geranyl diphosphate (C10), the monoterpene precursor behind menthol, carvone and citral. Another IPP gives farnesyl diphosphate (C15), behind artemisinin. Another gives geranylgeranyl diphosphate (C20), behind taxol and the andrographolides. Two farnesyl units joined tail to tail give squalene (C30), oxidised to 2,3-oxidosqualene and cyclised, in plants through cycloartenol, to the steroidal skeleton behind hecogenin, the guggulsterones, the withanolides, digitoxin's aglycone and the triterpenoid saponins. The table below fixes the chain lengths, the fastest check on any terpenoid answer.

Precursor	Carbons	Class built from it	Syllabus examples
Geranyl diphosphate (GPP)	10	Monoterpenoids	Menthol, carvone, citral
Farnesyl diphosphate (FPP)	15	Sesquiterpenoids	Artemisinin
Geranylgeranyl diphosphate (GGPP)	20	Diterpenoids	Taxol core, andrographolide
Squalene, then oxidosqualene	30	Triterpenoids and steroids	Hecogenin, guggulsterone, withanolides, glycyrrhizin, bacosides, cucurbitacins, digitoxin aglycone

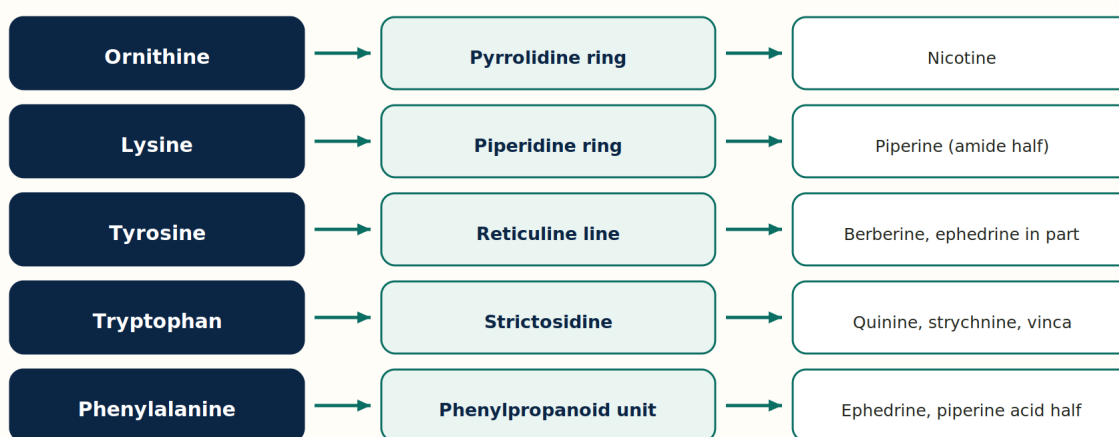
1.4 The amino acid pathways to the alkaloids

Alkaloids are nitrogen containing, typically basic and potent secondary metabolites, and biosynthetically they are the amino acid family's products. Ornithine gives the tropane alkaloids and supplies the pyrrolidine ring of nicotine. Lysine gives the piperidine and quinolizidine alkaloids and the piperidine ring of piperine's partner unit. Tyrosine is the most productive: two tyrosine derived units join in the benzyloquinoline pathway, which produces berberine and, by rearrangement, morphine's family; tyrosine also supplies ephedrine's skeleton in part. Tryptophan, through tryptamine, gives the indole alkaloids: joined with a monoterpene unit it produces strictosidine, the universal precursor of the monoterpene indole alkaloids, from which quinine's family, strychnine and the vinca alkaloids descend. Caffeine's purine skeleton comes from purine metabolism, not from an amino acid directly, and two syllabus names are mixed: piperine joins a lysine derived piperidine with a phenylpropanoid acid, and ephedrine a phenylalanine derived unit with a

three carbon unit. The origins map below collects the routes.

The pattern of an alkaloid pathway answer is constant. Name the amino acid precursor and the first committed intermediate where one is standard, strictosidine for the monoterpene indole alkaloids, reticuline for the benzyloquinolines. Then follow the skeleton building steps in outline, cyclisation, oxidation, methylation and rearrangement, to the finished alkaloid. Decarboxylation of the amino acid to its amine is a recurring first step, and Pictet-Spengler type condensation a recurring ring forming step.

Amino acid origins of the alkaloids



Name the amino acid first: the pathway answer follows from the precursor

© 2026 PharmacolLearn, pharmacollearn.fyi

Figure: The amino acid origins of the syllabus alkaloids. Tryptophan plus a monoterpene unit, through strictosidine, is the single most productive line in the unit.

1.5 Radio tracing techniques: how pathways are proved

A biosynthetic pathway cannot be seen: its intermediates are present in tiny amounts, turn over rapidly, and sit inside a living tissue running thousands of other reactions. Radio tracing, or radiotracer technique, is the classical method that made pathways provable, and the syllabus places it in this unit's title because the pathways taught around it rest on its evidence. A precursor is prepared with one or more atoms replaced by a radioactive isotope, most often carbon-14, with tritium, phosphorus-32 and sulfur-35 used for suitable questions. The labelled precursor is fed to the plant, by root or cut stem uptake, injection, leaf application or, for photosynthesis labelling, labelled carbon dioxide. After a chosen time the product is isolated, purified rigorously to constant radioactivity, and counted, usually by liquid scintillation counting. If the product is radioactive, the precursor's atoms reached it. The decisive refinement is degradation: the product is broken down step by step into defined fragments and each is counted. Radioactivity in exactly the positions the proposed pathway predicts, and absent where it predicts absence, proves the route and the order of its steps.

The standard working methods around the feeding experiment complete the technique. Autoradiography locates radioactivity in a tissue or on a chromatogram. Isotope dilution, adding unlabelled material to trap a fleeting intermediate, tests whether a suspected intermediate lies on the path. Double labelling, feeding two isotopes at once, tests whether part of a molecule is incorporated intact. Feeding suspected advanced intermediates, which should label the product more efficiently than an early precursor if the order is right, orders the steps. Stable isotopes, carbon-13 above all, are the modern partner: the label is followed not by counting but by NMR and mass spectrometry, which read its position directly, with no radiation hazard. The tracer workflow below shows the sequence of a classical proof.

```

Prepare the labelled precursor (14C or 3H at a known position)
|
Feed to the intact plant, tissue or culture; allow metabolism
|
Harvest, extract and isolate the target constituent
|
Purify to constant specific radioactivity
|
Measure incorporation (scintillation counting)
|
Degrade the product step by step; count each fragment
|
Label in the predicted positions only: pathway step confirmed

```

Radio tracing: proving a pathway



Purification to constant activity and degradation make the proof

© 2026 PharmacoLearn, pharmacolearn.fyi

Figure: The radio tracing workflow. Purification to constant activity and the degradation step are what separate a proof from a suggestion.

The interpretation rules are as examinable as the method. Incorporation must be specific, not the general labelling that results when a precursor is broken down to labelled carbon dioxide or acetate and rebuilt into everything; position specific degradation is the guard. A low incorporation does not refute a pathway, because the fed precursor is diluted by the plant's own pool. Failure to incorporate does not exclude a compound, which may simply not reach the site of synthesis. The result is strongest when several precursors label the product in mutually consistent positions. By this logic the mevalonate and shikimate routes, and the central places of strictosidine and reticuline, were established.

1.6 The alkaloid set: the pattern for biosynthesis, isolation, characterisation and purification

The syllabus asks for the named constituents under one combined head: biosynthesis, isolation, characterisation and purification, with special reference to their importance in the herbal industries. That head sets the pattern for Sections 1.6 to 1.12. For biosynthesis, give the precursor and route of Sections 1.2 to 1.4. For isolation, the general alkaloid method is the backbone: the drug is extracted with alcohol or dilute acid, and the alkaloids are liberated by making the aqueous extract alkaline, whereupon the free bases pass into an immiscible organic solvent; the bases are drawn back into dilute acid, the solution washed, basified and re-extracted, an acid base shuttle that separates bases from neutral and acidic companions. Individual alkaloids are separated by fractional crystallisation of their salts, column

chromatography and recrystallisation. For glycosides the method differs, because they are polar and often fragile: extraction is with water or aqueous alcohol, hydrolysing enzymes are inactivated early, tannins and pigments are removed, and purification is by crystallisation and chromatography, with care against acid and enzymatic hydrolysis throughout. For steroids, saponins and terpenoids, extraction follows polarity: non polar solvents for sapogenins after hydrolysis of their saponins, alcohol for the saponins themselves. Characterisation across all groups rests on one ladder: physical constants, class colour and precipitation reactions, chromatographic behaviour against reference standards, and the spectroscopic proof of Unit 5. Purification is judged by a single chromatographic spot or peak and constant physical constants.

1.7 Ephedrine and quinine

Ephedrine is the phenethylamine alkaloid of Ephedra species (Ma Huang), a sympathomimetic long used in pharmacy. Biosynthetically it is mixed origin: its phenylpropane skeleton derives from phenylalanine by way of cinnamic acid and a benzaldehyde stage, and the side chain is completed by condensation with a three carbon unit from pyruvate, followed by transamination and N methylation, the joining of a shikimate derived unit with a carbohydrate derived unit. Isolation follows the general alkaloid method, with the practical note that ephedrine is comparatively water soluble and steam volatile for an alkaloid. Ephedra extracts are standardised on their ephedrine alkaloids, and the same potency places them under strict regulatory control in many markets.

Quinine is the cinchona alkaloid of Cinchona bark, the historic antimalarial whose isolation is one of the founding events of Unit 2. Biosynthetically it is a monoterpene indole alkaloid with a rearranged skeleton: tryptamine condenses with secologanin to strictosidine, the pathway proceeds through corynanthe type intermediates, and the indole system is then rearranged and opened to build the quinuclidine ring. That rearrangement is the examinable surprise: quinine looks nothing like a simple indole alkaloid, yet tracer work places it firmly in the strictosidine family. Isolation is industrial alkaloid extraction from bark, the total cinchona alkaloids being separated into quinine, quinidine, cinchonine and cinchonidine by fractional crystallisation of their salts. Its stereoisomer quinidine is itself a medicine, a reminder that separation of near identical alkaloids is a core phytochemical skill.

1.8 Strychnine, piperine and berberine

Strychnine, from the seeds of *Strychnos nux-vomica*, is the most complex structure in this section. It is a monoterpene indole alkaloid: tryptamine and secologanin give strictosidine, and a long sequence of rearrangements, through intermediates of the Wieland-Gumlich type, folds the monoterpene unit around the indole nitrogen into strychnine's cage of fused rings. Its extreme potency as a convulsant is why it is taught: *Strychnos* seeds must be standardised and handled as the toxic drugs they are. Isolation follows the alkaloid shuttle, strychnine being separated from its companion brucine, the dimethoxy analogue occurring with it, by fractional crystallisation of salts.

Piperine is the pungent alkaloid of black pepper, *Piper nigrum*, and the unit's clearest mixed origin alkaloid. One half is piperic acid, a phenylpropanoid derived acid carrying a methylenedioxy group; the other half is piperidine, from lysine; the two are joined as an amide. Piperine is a standardised marker for pepper extracts and a well known inhibitor of drug metabolising enzymes and efflux transport in the gut, added to some formulations as a bioavailability enhancer and an interaction caution in its own right. Isolation is by alcohol extraction of the ground fruit and crystallisation from the concentrate.

Berberine is the yellow isoquinoline alkaloid of *Berberis* and related genera and of drugs such as daruharidra and coptis. It is a benzylisoquinoline alkaloid: two tyrosine derived units build reticuline, and berberine is formed from that line by the berberine bridge reaction, in which an enzyme converts the N methyl group of a reticuline type intermediate into the methylene bridge closing berberine's extra ring,

followed by oxidation to the fully aromatic, quaternary, intensely yellow berberinium system. That permanent charge explains its characterisation: berberine is handled as a salt, is strongly coloured, and is standardised by chromatographic assay against berberine reference standard.

1.9 Taxol and the vinca alkaloids

Taxol, paclitaxel, is listed by the syllabus with the alkaloids, and the honest classification note belongs in every good answer: paclitaxel is a taxane diterpenoid, built from geranylgeranyl diphosphate through the taxadiene skeleton, carrying a nitrogen containing side chain attached as an ester, which is why teaching lists group it loosely with the alkaloids; it is not an amino acid derived alkaloid of the Section 1.4 pattern. Its biosynthesis runs from GGPP to taxa-4(5),11(12)-diene, then through extensive oxygenation of the core, attachment of the phenylalanine derived side chain, and final acylations. The industry story is supply: the original bark source, *Taxus brevifolia*, could not supply the drug sustainably, and production moved to semisynthesis from baccatin type precursors from renewable yew needles and to plant cell culture. Isolation is the separation of one diterpenoid from hundreds of close taxane relatives by repeated chromatography, and characterisation is wholly spectroscopic.

The vinca alkaloids, vincristine and vinblastine from *Catharanthus roseus*, close the list with the unit's most instructive biosynthesis. Both are dimeric monoterpene indole alkaloids: the strictosidine route builds two monomers, catharanthine and, through tabersonine, vindoline, and oxidative coupling of the two gives the dimer anhydrovinblastine, from which vinblastine and, by oxidation of one methyl group to an aldehyde, vincristine are obtained. One small change separates the two drugs and their clinical profiles differ accordingly, so the separation and assay of the dimers, present in the leaf in very small amounts beside far larger amounts of their monomers, is an industrial chromatography problem of the first rank. *Catharanthus* joins this unit to Unit 2: a common ornamental plant, a tracer proved pathway, and two of the most important anticancer medicines taken from a plant.

1.10 The glycoside set: digitoxin, glycyrrhizin, sennosides, bacosides and quercetin

A glycoside is a constituent in which a sugar part, the glycone, is joined to a non sugar part, the aglycone or genin, and the pharmacology usually lives in the aglycone while the sugar governs solubility and transport. The five syllabus names span four chemical families, and the table fixes their classes before the paragraphs take each in turn.

Constituent	Source drug	Class	Aglycone or active part
Digitoxin	<i>Digitalis purpurea</i> leaf	Cardiac glycoside (cardenolide)	Digitoxigenin, a steroidal aglycone with an unsaturated five membered lactone
Glycyrrhizin	Liquorice root, <i>Glycyrrhiza glabra</i>	Triterpenoid saponin glycoside	Glycyrrhetic acid, an oleanane triterpene
Sennosides	Senna leaflets and pods, <i>Senna alexandrina</i>	Anthraquinone glycosides (dianthrone)	Sennidins, joined rhein type anthrone units
Bacosides	<i>Bacopa monnieri</i> herb	Triterpenoid saponin glycosides (dammarane type)	Jujubogenin and pseudojujubogenin type aglycones
Quercetin	Widespread in leaves, fruits and flowers, richly in onion and <i>Sophora</i> buds as its glycosides	Flavonol (flavonoid), occurring in plants chiefly as glycosides such as rutin	Quercetin itself is the aglycone

Digitoxin biosynthesis is steroidal: the aglycone is built from the acetate mevalonate route through squalene and the sterol line, with the cardenolide's unsaturated five membered lactone formed at the side

chain, and three digitoxose units attached by glycosylation; the digitoxoses are deoxy sugars, a characterisation point examiners use. Isolation is the classical careful extraction: rapid enzyme control, defatting, aqueous alcoholic extraction, and purification distinguishing the leaf's primary glycosides from secondary glycosides such as digitoxin, formed by loss of a terminal glucose.

Glycyrrhizin, the sweet principle of liquorice, is built from oxidosqualene cyclised to the oleanane skeleton of beta amyrin, oxidised to glycyrrhetic acid and glycosylated with two glucuronic acid units. It returns in Unit 5 as a full structure elucidation example. Industrially it is extracted from the root with water or aqueous alcohol, isolated through its salts, and liquorice extracts are standardised on it.

Sennosides A and B are dianthrone glycosides: their anthraquinone ring system is polyketide in origin, the aglycone units are rhein anthrone type halves joined into the dianthrone, and glucose units complete the glycosides. Senna is standardised on the sennosides, isolated by aqueous alcoholic extraction protected against oxidation and hydrolysis, and characterised by the Borntrager type colour reaction together with chromatographic assay.

Bacosides are the dammarane type triterpenoid saponins of *Bacopa monnieri*, brahmi, built from oxidosqualene and glycosylated; bacopa extracts are standardised on total bacosides, the standardisation of a mixture of close saponins rather than of one crystal.

Quercetin carries the classification note flagged in the verification record. Quercetin itself is an aglycone, the flavonol at the centre of a large family; in the plant it occurs overwhelmingly in glycosidic form, as rutin (quercetin with rutinose, from *Sophora* buds and buckwheat), quercitrin and other glycosides, which is why the syllabus lists it with the glycosides. Its biosynthesis is the mixed shikimate and acetate pattern of Section 1.2: the B ring from phenylalanine through the phenylpropanoid route, the A ring from three malonate units, joined in the chalcone and cyclised to the flavonoid skeleton, then hydroxylated to quercetin's pattern. Unit 5 returns to its close relatives luteolin and kaempferol.

1.11 The steroid set: hecogenin, guggulsterone and withanolides

The syllabus word steroids here covers the steroidal and triterpenoid products of the squalene line, and the three names show its three industrial faces. **Hecogenin** is a steroidal sapogenin, the aglycone of the saponins of *Agave* and related plants, built from the sterol line by spiroketal ring formation at the side chain. Its importance is as an industrial starting material: sapogenins such as hecogenin and diosgenin were the raw materials from which steroid hormones and corticosteroids were semisynthesised, because the plant supplies the finished steroid nucleus. Isolation runs through hydrolysis of the saponins and crystallisation of the sapogenin.

Guggulsterone, met in the previous subject as the marker of guggulipid, is the steroidal ketone pair, the E and Z isomers, from the oleo gum resin of *Commiphora wightii*. Its origin is the sterol line with oxidative trimming to the pregnane type skeleton. Guggul extracts are standardised on total guggulsterones, the E and Z pair separated and measured chromatographically, a neat example of isomer aware standardisation.

Withanolides are the steroidal lactones of *Withania somnifera*, ashwagandha root, a family rather than one compound: a steroidal skeleton carrying a six membered unsaturated lactone in its side chain, withaferin A and the withanosides among the named members, built from the sterol line by side chain oxidation and lactonisation. Ashwagandha extracts are standardised on total withanolides, a defined sum of named members measured by chromatography, not an imagined single active.

1.12 Umbelliferone and the cucurbitacins

Umbelliferone is the syllabus coumarin, 7-hydroxycoumarin, widespread in the Apiaceae and named from the umbelliferous plants. Its biosynthesis is the phenylpropanoid pathway in miniature: phenylalanine gives cinnamic acid, hydroxylation gives p coumaric acid, ortho hydroxylation and isomerisation set up the ring closure, and lactonisation closes the coumarin ring. Coumarins are characterised by their fluorescence under ultraviolet light, strengthened in alkali, used in their chromatographic detection.

The cucurbitacins are the terpenoids of the unit: intensely bitter, highly oxygenated triterpenoids of the Cucurbitaceae, built from oxidosqualene through the cucurbitadienol skeleton and then extensively oxidised. Their bitterness at extremely low concentration and their cytotoxicity make them chemical defence compounds for the plant, safety markers for cucurbit drugs and foods, and research leads at once.

1.13 Importance in the herbal industries, and Unit 1 in one view

A biosynthetic pathway, once known, tells industry four practical things. It tells the grower which plant, organ and stage carries the most constituent, because accumulation follows the pathway's site and season. It tells the breeder and biotechnologist which steps limit production, and therefore which varieties to select and which genes a cell culture programme must keep switched on. It tells the manufacturer what else the extract will contain, the pathway's neighbours that standardisation must measure or control. And it tells the analyst which compounds are genuine markers, since a true biosynthetic product of the species is a far stronger identity marker than an added chemical. Unit 1 in one view: primary metabolism supplies four building block systems; the named phytopharmaceuticals are assembled from them by ordered pathways; radio tracing, with stable isotope work beside it, proved those pathways; and the general group methods of isolation, characterisation and purification turn the product into a standardised industrial constituent.

More free M.Pharm notes and unit wise PDFs at pharmacolearn.fyi
Free video lectures on the PharmacoLearn YouTube channel