Appendix One: Forensic Science Service – Methylamphetamine

THE FORENSIC SCIENCE SERVICE

FSS REPORT ON

METHYLAMPHETAMINE

CHEMISTRY, SEIZURE STATISTICS, ANALYSIS, SYNTHETIC ROUTES AND HISTORY OF ILLICIT MANUFACTURE IN THE UK AND THE USA

FOR

THE ACMD WORKING GROUP ON METHYLAMPHETAMINE

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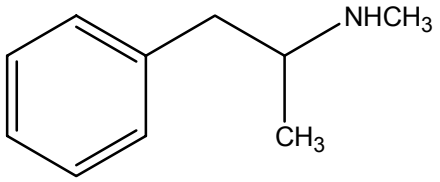
Structure and Chemistry

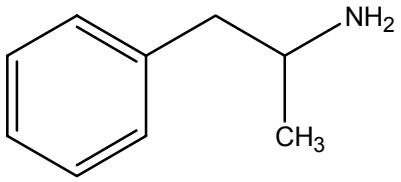
Methylamphetamine is a synthetic drug closely related to amphetamine. Alternative chemical names for methylamphetamine include:

deoxyephedrine	methedrine
desoxyephedrine	2-methylamino-1-phenylpropane
N, α-dimethylbenzeneethanamine	*N*-methylamphetamine
N, α-dimethylphenethylamine	pervitine
metamfetamine	phenylisopropylmethylamine
methamphetamine	1-phenyl-2-methylaminopropane

The chemical structures are shown below.

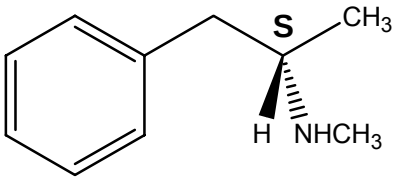


Methylamphetamine

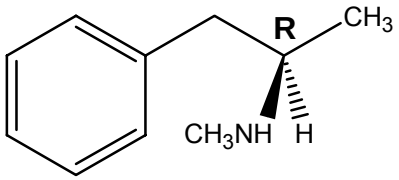


Amphetamine

Amphetamine and methylamphetamine have a chiral centre (an asymmetric carbon atom attached to four different substituents) giving rise to two stereoisomers, known as optical isomers, which are mirror images of each other. The structures of the optical isomers of methylamphetamine are shown below:



S (+)-Methylamphetamine
d-methylamphetamine



R (-)-Methylamphetamine
l-methylamphetamine

The *S* stereoisomer of methylamphetamine (*d*- or (+)- methylamphetamine) is the most potent in terms of CNS stimulant activity.

The R stereoisomer (*l*- or (-)-methylamphetamine) is a decongestant and in the US is an ingredient of the Vicks inhaler. It is also used as a precursor for the manufacture of selegiline (Cheng, 2002).

From a chemical point of view, the only difference between amphetamine and methylamphetamine is that the latter is a secondary amine with an *N*-methyl group, whereas amphetamine is a primary amine. Some selected physical properties of these drugs are shown in Table 1.

Table 1: Physical properties of amphetamine and methylamphetamine

Property	AMP	MA	Reference
Boiling point ºC (d- base)	203-204	208-210	UN, 1987
Boiling point ºC (dl- base)	200-203	209-210	UN, 1987
Melting point ºC (dl- hydrochloride salt)		131-135	UN, 1987
Melting point ºC (d- hydrochloride salt)	- 156.5-158.5	170-175 -	2004a Rozwadowska, 1993
Melting point ºC (d- sulphate salt)	300 (decomp)	-	UN, 1987
Melting point ºC (dl- sulphate salt)	280-281	-	UN, 1987
Dissociation Constant (pKa)	10.1 9.9	10.1 10.1	2004a 1986a
Partition Coefficient Log *P*(octanol/water)	1.8 -	2.1 2.3	2004a Rivière *et al*, 2000

AMP= Amphetamine; MA=Methylamphetamine

Both drugs are slowly volatile liquids and therefore are normally encountered as their salts, which are water soluble, micro-crystalline powders.

In water, secondary amines are generally more basic than primary amines. However, the pK_a for methylamphetamine is the same or only slightly higher than that for amphetamine. At the pH of biological fluids (pH 7.4), the proportion of methylamphetamine (pK_a 10.1) in the non-ionised form (free base) is calculated to be 6.3%, whereas for amphetamine (pK_a 9.9) the proportion in the non-ionised form would be 7.6%. The availability of lipid soluble methylamphetamine base in biological fluids is therefore calculated to be only about 17% less than for amphetamine.

Methylamphetamine has an *N*-methyl group and is therefore predicted to be more lipid-soluble than amphetamine. This is supported by the octanol/water partition coefficients, which provide a measure of lipophilicity of the free base form of the drugs. However, the difference is small and both drugs are highly lipid soluble.

Methylamphetamine is usually encountered in illicit seizures as the hydrochloride salt whereas amphetamine is most often encountered as the sulphate salt. Methylamphetamine and amphetamine are usually encountered as powders or tablets.

'ICE' is a smokable form of methylamphetamine consisting of large transparent, colourless crystals of virtually pure methylamphetamine hydrochloride. Confusingly, "ICE" has been used as a slang term for other illicit drugs, including cocaine hydrochloride, mixtures of methylamphetamine and "Crack" cocaine, and heroin and "Crack", and 4-methyl-aminorex ("Euphoria") (Owen, 1990). More recently, the term "ICE" has been used for lignocaine because of the way it freezes the face when snorted.

Pure *d*-methylamphetamine hydrochloride has a melting point of 170-175°C and in 'smoking' experiments it has been vaporised without decomposition at 200°C (Meng, 1997) and at 300-305°C (Cook, 1993). The racemate, *dl*-methylamphetamine, has a lower melting point (131-135°C). Methylamphetamine can therefore be administered by smoking in the same way as 'crack' cocaine. Note however, that cocaine hydrochloride melts at 197°C (1986a) with decomposition and is therefore not suitable for smoking; it needs to be converted to the more volatile cocaine base ('crack' cocaine), which has a lower melting point (97-98°C) and is volatile above 90°C (1996a).

Reefer cigarettes containing 20 milligrams of amphetamine have been prescribed at a drug dependency clinic (Marks, 1990), but smoking of illicit amphetamine does not appear to be common. Pure *d*-amphetamine sulphate melts at about 300°C with decomposition and is therefore not suitable for smoking, although there is a report on the Internet of the drug being recovered from 'DextroStat' tablets. The binders were removed and the residual *d*-amphetamine sulphate was smoked through a glass vaporising pipe (2004b). The racemic *dl*-amphetamine sulphate, usually found in illicit seizures, has a lower melting point (280-281°C) than the pure *d*-amphetamine sulphate stereoisomer.

Pure *d*-, *l*- and *dl*-amphetamine hydrochloride are commercially available[1] and their preparation is described in the scientific literature. Amphetamine hydrochloride has been encountered in illicit preparations in the USA (Morales, 1999) although it is uncommon and there are no records of it being encountered in UK drug seizures.It is reported to be extremely hygroscopic (Hey, 1930) and difficult to handle when anhydrous (Rozwadowska, 1993) which may account for the prevalence of amphetamine sulphate. Amphetamine hydrochloride has a melting point of about 157°C and although no data was found on its volatility it should vaporise at a similar temperature to methylamphetamine hydrochloride.

Amphetamine base, is a volatile liquid, so in theory, amphetamine sulphate could be smoked by converting it to the base *in situ* by heating with sodium bicarbonate powder.

Analysis of Methylamphetamine

Amphetamine and methylamphetamine, and their salts and stereoisomers are controlled by the Misuse of Drugs Act, 1971, as Class B drugs and as Class A drugs when in the form of a preparation designed for administration by injection. However, in most cases it is not necessary for the forensic scientist to identify the particular salt or stereoisomer. Purity is not normally required in cases of possession.

Identification of methylamphetamine and cutting agents

In the FSS laboratories, amphetamine and methylamphetamine are usually identified by gas chromatography-mass spectrometry (GC-MS). The chromatograms and mass spectra

[1] For example, Lipomed AG, CH 4144 Arlesheim, Switzerland

of these drugs are not very characteristic and therefore the drugs are usually derivatised before analysis by GC-MS. The salt form is not usually determine, but when required, the salts can be identified by infra-red spectroscopy (IR) or X-ray diffraction (XRD). Methods have been published for the identification of individual stereoisomers (Lui, 2002 and Cheng, 2002), but these are not routinely available in the FSS laboratories.

Impurity profiling

Illicit amphetamine and methylamphetamine are complex mixtures containing additives, often referred to as cutting agents or adulterants, together with by-products from the manufacturing process and impurities from the precursors. These substances are not routinely identified unless there is a specific requirement, e.g. in comparison cases. However, some may be detected during the routine GC-MS analysis or by IR or XRD analysis.

The relative amounts of the impurities in illicit amphetamine and methylamphetamine may show large variations, which are attributed to the exact nature of starting materials, the synthetic route, actual manufacturing conditions employed by the illicit laboratory 'chemist', cutting agents added, storage conditions and method of distribution.

Impurity profiling involves detailed chemical analysis of the impurities to produce a "fingerprint" known as an impurity profile. By comparing impurity profiles it is possible to show whether or not two samples are likely to have been produced from the same batch, or by the same illicit laboratory/recipe or by the same synthetic route, depending on the similarities between profiles. Impurity profiling is therefore a useful tool for both evidential and intelligence purposes.

The FSS routinely uses amphetamine impurity profiling to provide evidence of linked seizures in supply cases. As part of the EU CASE (Comprehensive Action against Synthetic Drugs in Europe) Project, the FSS also sends samples of all amphetamine seizures larger than 500 grams to the Swedish National Laboratory of Forensic Science (SKL) for impurity profiling.

The UN have developed a method for impurity profiling of methylamphetamine samples (Remberg, 1999) and profiling methods have been used in Thailand (Puthaviriyakorn, 2002), Japan (Inoue, 1994), Australia (Perkal, 1994), the United States (Lurie, 2000, and Koester, 2002) and the Philippines (Dayrit, 2004). Methylamphetamine profiling is not routinely available in the FSS.

Manufacturing impurities or their metabolites may also be detected in body fluids and tissue samples taken from methylamphetamine users (Moore, 1995 and Moore, 1996b).

Drug field testing

Law enforcement officers often use a drug field test for the presumptive identification of a controlled drug and, for amphetamines, the most widely used field-test is the Marquis

reagent. In guilty plea cases, police officers can only use Marquis test reagents approved by the Home Office and can only test for morphine, heroin and amphetamine. At present only Marquis test reagents produced by NIK (Narcotics Identification Kit)[2], ESA[3] and BDH[4] have been approved (2002a).

The BDH Marquis reagent consists of a glass ampoule containing a solution of formaldehyde in concentrated sulphuric acid. The Marquis test is carried out by opening the ampoule and adding a very small amount of powder and then observing the colour change within the first minute. Amphetamine gives an orange colour, which turns brown, whereas methylamphetamine just gives an orange colour. However, the presence of diluents such as glucose and lactose may cause charring (brown to black colour) which can easily mask the difference between amphetamine and methylamphetamine.

Various colours representing the whole of the visible spectrum are given by a large number of other drugs (1986a).

If methylamphetamine were re-classified as a Class A drug, it would be important for law enforcement officers to have a drug field test to discriminate between methylamphetamine and amphetamine.

The Simon test (UN, 1994) for secondary amines can be used to discriminate between amphetamine and methylamphetamine. A small amount of the drug is placed on a white spotting tile and one drop of 20% sodium carbonate solution is added followed by one drop of 50% ethanolic acetaldehyde solution. Addition of a few drops of 1% aqueous sodium nitroprusside solution produces a blue colour for methylamphetamine and other secondary amines. Amphetamine and other primary amines yield a slow pink to cherry-red colour. The presence of some cutting agents may result in false positives (UN, 1987).

Field tests to discriminate between amphetamine and methylamphetamine are available commercially but at present none are authorised by the Home Office for use in guilty plea cases. Some examples are described below:

The 'Meth-Test' is a modified Simon test produced by Erez (2004c). The field test kit contains two 'Meth-Test' spray cans and a box of special test papers. The drug is placed on the test paper and then sprayed with 'Meth Test #1' followed by 'Meth Test #2'. A blue colour indicates the presence of methylamphetamine or other secondary amine.

The NIK test[2], 'Test U', is designed to be used as part of a sequence of tests for amphetamine and methylamphetamine. The test appears to be based on the Simon test. The reagents are contained in three glass ampoules in plastic sleeves inside a transparent plastic pouch. A small amount of the drug is placed in the pouch, which is then closed and the ampoules are broken in the specified sequence. A red colour indicates the

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[2] Marketed by Crack-Down Drug Testing of Unit 11, Boarshurst Business Park, Boarshurst Lane, Greenfield, Saddleworth, OL3 7ER
[3] Marketed by Rix-Walker Ltd, 27 Barrards Way, Seer Green, Beaconsfield, Bucks HP9 2YZ
[4] Produced by Merck Ltd of Merck House, BDH Laboratory Supplies, Poole, Dorset, BH15 1TD

presence of amphetamine type drugs and a blue colour indicates the presence of methylamphetamine. The colour obtained can be compared to blue and red coloured squares printed on the pouch.

Illicit manufacture of methylamphetamine

Numerous methods for the production of methylamphetamine are readily available from the scientific literature, patents, published books (Fester, 1989 and Snow, 1998) and the Internet (2004e). Many of the methods are analogous to those used for amphetamine and ring substituted phenethylamines (e.g. 'ecstasy' drugs). The choice of method depends any many factors, however from a scientific point of view the main factors are availability of precursors and other chemicals, complexity of the process, availability of equipment, and chemical hazards.

Methylamphetamine is relatively easy to manufacture. In the US, less than 10% of those arrested for illicit synthesis of methylamphetamine are trained chemists (Hargreaves, 2000).

Many different chemicals can be used in the production of methylamphetamine. These fall into three categories; precursors (the basic chemical 'building blocks'), reagents (to chemically modify or combine precursors in a chemical reaction) and general-purpose chemicals (solvents, acids, alkalis, etc to facilitate the reaction and isolate the product). In the US, UK and other countries, the sale of precursors, some reagents and some general-purpose chemicals is regulated by legislation and/or monitored by law enforcement agencies.

Chemicals, scientific glassware and equipment may be obtained from chemical suppliers or imported. However, many illicit 'chemists' have found that they can obtain many of the chemicals from readily available commercial products, laboratory glassware can be replaced with household items and equipment can be improvised or purpose built. A brief search of recent sales on the Internet auction site eBay found that all the equipment and precursors needed to produce large quantities of methylamphetamine were readily available (Borngasser, 2004).

Illicit laboratories represent a substantial health and safety threat to communities. Many of the chemicals are toxic, highly flammable, or corrosive. Fires and explosions are a constant threat in this type of environment. In the US during 2002, there were 694 fires/explosions as a direct result of illicit laboratories (Placido, 2004).

Traffickers often dispose of chemicals improperly, creating environmental problems that require expensive clean up. The production of one kilogram of methylamphetamine releases poisonous gas into the atmosphere and creates 5 to 7 kilograms of toxic waste. Many laboratory operators dump the toxic waste down household drains, in fields and yards, or on rural roads (ONDCP, 2003).

The small-scale laboratories are often more dangerous that the large-scale laboratories as the 'chemists' are inexperienced in the handling of hazardous chemicals. This is evident from the large number of children present at illicit laboratory sites. In 1999, children were reported to be at 870 out of 7,200 illicit laboratories seized in the US. Of these, 180 were exposed to toxic chemicals and 12 had chemical injuries (Kelly, 2002). In 2003 the number of children present at illicit laboratories had increased to 3,723. Of these, 42 were injured and 3 were killed (Placido, 2004).

Most of the methods for producing methylamphetamine use either phenyl-2-propanone, *l*-ephedrine or *d*-pseudoephedrine as precursors. Phenyl-2-propanone (P2P) is also known as phenylpropanone, phenylacetone and benzylmethylketone (BMK).

In the UK, the manufacture and the placing on the market of these precursor chemicals is regulated by the Controlled Drugs (Substances Useful for Manufacture) (Intra-Community Trade) Regulations 1993. The exportation of these precursors from, and their importation to, the European Community is regulated by the Controlled Drugs (Substances Useful for Manufacture) Regulations 1991 and Amendment 1992. However, these regulations do not at present apply to medicinal products.

Phenyl-2-propanone is not readily available in the UK but can be imported or synthesised from other chemicals.

In the US and the UK ephedrine and pseudoephedrine are available as over-the-counter medicines although in the US there are restrictions on the amounts that can be purchased in a single transaction and in the UK tablets containing more than 60 milligrams are only available on prescription.

Some over-the-counter medicines contain other drugs in addition to ephedrine or pseudoephedrine. Identification of these other drugs or their by-products in illicit methylamphetamine can provide useful information on the precursor source (Jacobs, 2003).

Some attempts have been made to design inhibitors that can be added to over-the-counter medicines to prevent them being used for manufacturing methylamphetamine. The inhibitors interfere with the isolation of ephedrine and/or interfere with the conversion of ephedrine to methylamphetamine. Suggested inhibitors include an aminoalkyl methacrylate copolymer (Eudragit-E®), ferrous gluconate, lactose, ethylcellulose, and hydroxypropyl cellulose (Bess, 2002).

Ephedrine can also be extracted from *Ephedra* plant products. The stems and leaves of the Mediterranean and Asiatic species of *Ephedra* contain ephedrine and pseudoephedrine, both of which can be used to produce methylamphetamine (Andrews, 1995; Hutchinson, 1995; and Pederson 1994). The *Ephedra* plant also contains smaller amounts of four other related alkaloids: norephedrine, norpseudoephedrine, methylephedrine, and methylpseudoephedrine. Consequently, methylamphetamine made from *Ephedra* extracts usually contains some *N*,*N*-dimethylamphetamine (from reduction

of methylephedrine and methylpseudoephedrine) and traces of amphetamine (from reduction of norephedrine and norpseudoephedrine).

Ephedrine is easily isolated from *Ephedra* using common solvents and other chemicals, but a simple methanol extract can be used.

A summary of the most important methods are given below:

Phenyl-2-propanone Methods

Phenyl-2-propanone (P2P) is frequently used as a precursor in the production of amphetamine.

Leuckart Reaction

Phenyl-2-propanone, formamide and formic acid are heated together to produce *N*-formylamphetamine. This intermediate is an amide, which can be hydrolysed with hydrochloric acid to yield amphetamine (typical yield, 41%).

Methylamphetamine can be produced by reduction of the *N*-formylamphetamine intermediate with lithium aluminium hydride (typical yield, 41%) (Červinka, 1968).

Methylamphetamine can also be produced by replacing the formamide with *N*-methylformamide, which can be produced *in situ* from methylamine and formic acid. The intermediate amide, *N*-formyl-*N*-methylamphetamine, is hydrolysed with hydrochloric acid to produce methylamphetamine (typical yield, 43%) (Crossley, 1945).

Reductive amination methods
The simplest of these is the aluminium amalgam method. Phenyl-2-propanone and methylamine in alcohol are combined to produce an intermediate Schiff's base, which reacts with a reducing agent to produce methylamphetamine. Activated aluminium (aluminium amalgam) is a readily available reducing agent obtained from aluminium foil or turnings and a small amount of mercuric chloride. Cooling is required if the reaction becomes too violent (typical yield 70%) (Temmler-Werke,1940, 1964a, Wassink, 1974).

Nitromethane can be used in place of methylamine as it is reduced to methylamine *in situ* (Snow, 1998).

Amphetamine can be produced in the same way using ammonia or hydroxylamine in place of methylamine, but yields are lower (typically 30%).

Reductive amination of phenyl-2-propanone can also be achieved with other reducing agents including, sodium borohydride (2004e), sodium cyanohydridoborate (Borch, 1971), sodium metal (Ogata, 1919), hydrogen with a platinum (Tsutsumi, 1953),

palladium (Rosenmund, 1942) or Raney nickel catalyst (Allen, 1989). These reagents are less readily available and more hazardous than aluminium.

Reductive amination of phenyl-2-propanone using *N*-benzylmethylamine and hydrogen with a palladium catalyst produces *N*-benzylmethylamphetamine, which is subsequently reduced to methylamphetamine in the same reaction (Skinner, 1993).

Reductive aminations can be very dangerous, as there is a risk of explosion from hydrogen produced or used in the reaction. The waste products may also be pyrophoric when dry. Reductions with hydrogen are carried out in purpose built pressure vessels.

Ephedrine and pseudoephedrine methods

Ephedrine and pseudoephedrine have a reactive benzyl alcohol group, which can be reduced with a variety of reducing agents to produce methylamphetamine.

Amphetamine can be produced in the same way using norephedrine or norpseudoephedrine in place of ephedrine or pseudoephedrine. However, the two stereoisomers of norpseudoephedrine, *d*-norpseudoephedrine also known as cathine, and *l*-norpseudoephedrine, are controlled drugs (Class C). The two stereoisomers of norephedrine, when present as a racemic mixture, are known as phenylpropanolamine, a decongestant drug. Phenylpropanolamine is excluded from controlled by the Misuse of Drugs Act, 1971 and was an ingredient of over-the-counter medicines. However, phenylpropanolamine products are no longer available in the UK.

Reduction with sodium or lithium in anhydrous liquid ammonia (Birch or 'Nazi' method)
The use of sodium in anhydrous liquid ammonia (liquefied ammonia gas) for the reduction of benzyl alcohols was described by Birch in 1945 and in 1971 Hall *et al* investigated the use of lithium in liquid ammonia for this reaction. The application of this method to the illicit production of methylamphetamine from *l-e*phedrine was reported by Ely and McGrath in 1990 (Ely, 1990). Reduction of ephedrine or pseudoephedrine with lithium in anhydrous liquid ammonia is now erroneously known as the Birch or 'Nazi' method. The origin of the term 'Nazi' method is uncertain (Dal Cason, 1997).

The Birch method is relatively simple and quick, but sodium, lithium and anhydrous liquid ammonia are very hazardous chemicals. This method is therefore more suited to small-scale production, typically ounce quantities.

Lithium is readily available from lithium batteries, ammonia gas can easily be produced from ammonium salt fertilisers and caustic soda (sodium hydroxide), and anhydrous liquid ammonia can be obtained from agricultural sources. Some research has been carried out to find inhibitors that can be added to agricultural grade liquid ammonia making it unusable in the Birch method. The inhibitors are designed to scavenge solvated electrons, which is the reducing agent generated when lithium or sodium is dissolved in anhydrous liquid ammonia. Proposed inhibitors include iron(III) citrate,

ferrocene, 2-chloro-6-(trichloromethyl) pyridine and 1,1,1,2-tetrafluoroethane (Kelly, 2002, and Murray 2002).

A simple "one-pot" process based on the Birch method is available on the Internet (Mighty, 2004) and has been validated by forensic scientists in the United States (Pearson, 2004). All of the ingredients are placed into a 2-litre bottle. Pseudoephedrine is obtained from crushed tablets. Ammonia is generated *in situ* from ammonium nitrate fertiliser in a small amount of water with periodic addition of portions of 'Red Devil' lye (sodium hydroxide). Starting fluid (diethyl ether) was used as a solvent and lithium was obtained from 'AA' batteries. After several hours most of the pseudoephedrine is converted to methylamphetamine. The mixture is then filtered to produce a solution of methylamphetamine in diethyl ether. The hydrochloride salt of methylamphetamine is then formed as white crystals by introducing hydrogen chloride gas made in another bottle from sodium chloride (salt) and Liquid Fire drain opener (sulphuric acid).

Reduction with hydriodic acid and red phosphorus

This method for reducing a benzyl alcohol group has been known for many years. The application of the method to production of methylamphetamine has been described by Kishi *et al* in 1983 (in Japanese) and by Skinner in 1990 (typical yield 54-82%) (Skinner, 1990). Ephedrine or pseudoephedrine is heated with red phosphorus and hydriodic acid to produce methylamphetamine. The method is very simple and can be used for large-scale production.

Amphetamine can be produced in the same way by using norephedrine (phenylpropanolamine) or norpseudoephedrine (cathine) as a precursor.

Small amounts of red phosphorus can be recovered from matchbox strikers and various incendiary devices. White phosphorus has also been used in place of red phosphorus, but white phosphorus is more dangerous as it spontaneously ignites when exposed to air.

Hydriodic acid can be made *in situ* from red phosphorus, iodine and water, but phosphorous acid is produced as a by-product. If the reaction mixture is over heated, phosphorous acid breaks down to produce phosphine gas, which is extremely toxic and can ignite spontaneously. In 1996 in California, three individuals died from phosphine poisoning whilst making methylamphetamine using the iodine, water and red phosphorus method. A similar incident, also involving the death of three individuals, was encountered in California in 1985 (Willers-Russo, 1999).

Hydriodic acid can also be produced *in situ* from hypophosphorous acid and iodine. Reduction of ephedrine or pseudoephedrine with iodine and hypophosphorous acid does not require the use of red phosphorus as hypophosphorous acid acts as a reducing agent in the same way as red phosphorus. Although phosphorous acid is also produced as a by-product in this method, hypophosphorous acid also breaks down to produce phosphine, but at a much lower temperature than for phosphorous acid. Production of methylamphetamine using the iodine/hypophosphorous acid method (known as the

‘Hypo’ method) is therefore even more dangerous than the iodine/red phosphorus method (2003a).

Phosphorous acid can also be used as an alternative to hypophosphorous acid.

Emde Method

Ephedrine and pseudoephedrine can be converted to methylamphetamine via other chemical intermediates, but these methods are more complex than those described above. The most important of these is the Emde method, which is a two step process (Emde, 1929a and Emde,1929b). In the first step ephedrine is converted to chloroephedrine using thionyl chloride or phosphorus pentachloride in chloroform (yield 99.4%). In the second step the chloroephedrine is converted to methylamphetamine using hydrogen and a palladium catalyst in sodium acetate buffer solution (yield 80-90%).

Production and cutting of “ICE”

To produce “ICE” crystals, methylamphetamine hydrochloride is dissolved in water or isopropanol to make a saturated solution which is then allowed to stand in a refrigerator at 4°C. The formation of large crystals of “ICE” can take several weeks (Owen, 1990).

In 1990, high-purity ‘ICE’ methylamphetamine (80- to 90-percent pure methylamphetamine with a crystalline appearance) started to appear in North America (Owen, 1990). In the US, ‘ICE’ is now defined by the Federal Sentencing Guidelines as *d*-methylamphetamine with a purity greater than 80%. Offences relating to ‘ICE’ are more severe than for lower purity methylamphetamine.

One of the attractions of “ICE” crystals was believed to be that users would recognise it as high purity methylamphetamine, because it could not easily be cut in the same way as powders. However, in 1996 a seizure in Hawaii, was found to be a mixture of *d*-methylamphetamine hydrochloride crystals and dimethyl sulphone crystals (Chappell, 1996).

In 1998 in California, dimethyl sulphone was reported to be a common cutting agent of *d*-methylamphetamine (Sorgen, 1998). Dimethyl sulphone forms transparent crystals, which melt at 109°C and sublime slowly at 85°C. As a cutting agent, it would not therefore be readily detected by drug users. In California, the mixture was usually an intimate solid not a simple mixture of crystals. It is not known how the solid mixture is formed. Most likely the methylamphetamine hydrochloride and dimethyl sulphone are melted together and allowed to cool to form a uniform solid.

Cutting of “ICE” may also be used to avoid the higher sentences for purities greater than 80%, however, concentrations of methylamphetamine hydrochloride in these mixtures were frequently 10% or less (Morales, 1999).

In 2003, a seizure in Italy of 100 grams of "ICE" was actually found to contain 1.2 to 35% percent methylamphetamine cut with alum crystals (aluminium potassium sulphate) (2003b).

Stereo-chemical aspects methylamphetamine synthesis

Synthesis of methylamphetamine (or amphetamine) from phenyl-2-propanone always produces *dl*-methylamphetamine (or *dl*-amphetamine), a racemic (50:50) mixture of the two possible stereoisomers.

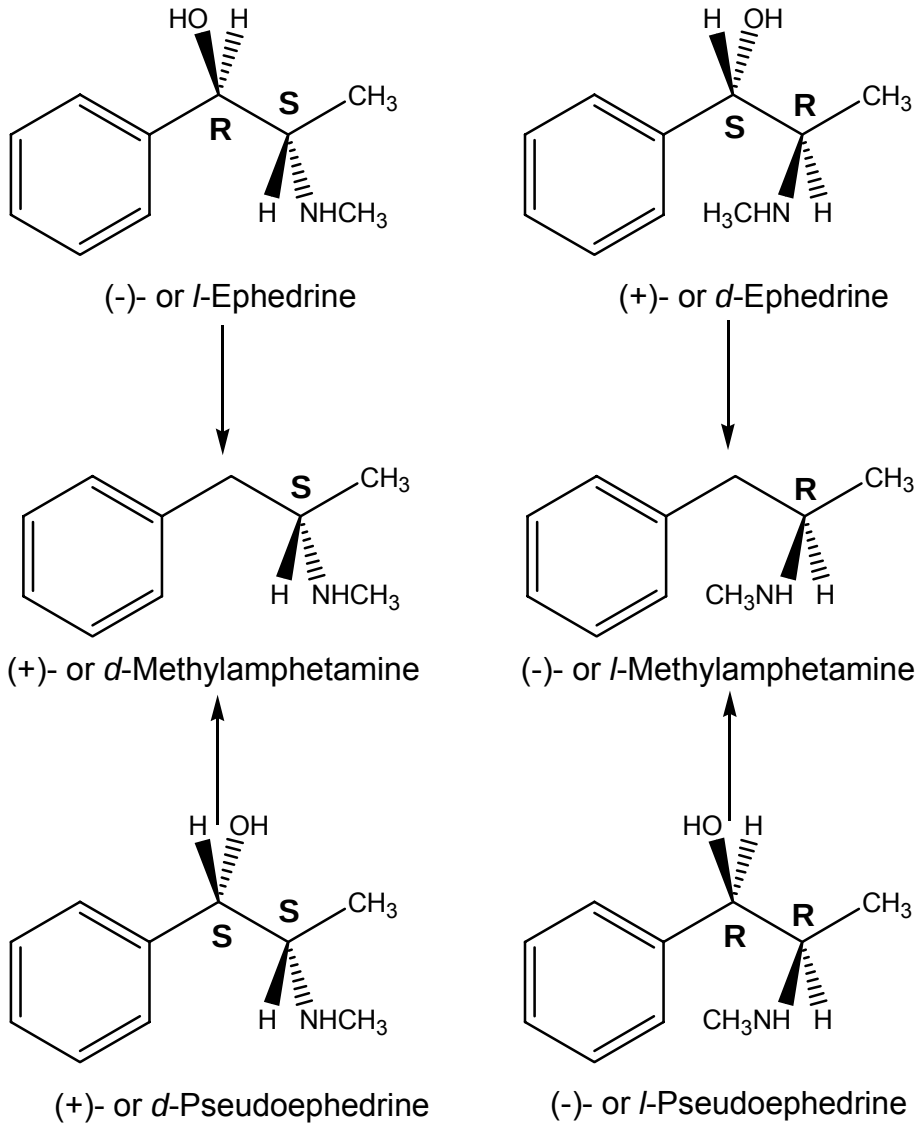
However, the isomeric composition of methylamphetamine produced from ephedrine or pseudoephedrine depends on that of the precursor. The more CNS active *d*-methylamphetamine stereoisomer is produced from *l*-ephedrine or *d*-pseudoephedrine, whereas, the use of *d*-ephedrine or *l*-pseudoephedrine leads to the production of the CNS inactive *l*-methylamphetamine (Figure 1).

In the British Pharmacopoeia (1998a), ephedrine hydrochloride is defined as (1*R*,2*S*)-2-methylamino-1-phenylpropan-1-ol hydrochloride, which is the *l*-ephedrine hydrochloride stereoisomer and pseudoephedrine hydrochloride is defined as (1*S*,2*S*)- 2-methylamino-1-phenylpropan-1-ol hydrochloride, which is *d*-pseudoephedrine hydrochloride stereoisomer. In the UK therefore, over-the-counter products of ephedrine and pseudoephedrine can be used to produce the *d*-methylamphetamine stereoisomer.

The stems and leaves of the Mediterranean and Asiatic species of *Ephedra* contain *l*-ephedrine and *d*-pseudoephedrine, therefore synthesis of methylamphetamine from *Ephedra* plant products always produces the *d*-methylamphetamine stereoisomer.

A recent seizure of methylamphetamine at an illicit "ICE" laboratory in California was unusual in that some of the drug was pure *l*-methylamphetamine. Non-racemic mixtures of *l*- and *d*-methylamphetamine with excess *l*-methylamphetamine were also encountered (2004d).

Figure 1



In Hong Kong the analysis of 138 methylamphetamine samples from 126 cases revealed that 80% contained optically pure *d*-methylamphetamine, 10% contained optically pure *l*-methylamphetamine and the remaining 10% contained various non-racemic mixtures of the two stereoisomers of methylamphetamine (Cheng, 2002).

The finding of relatively pure *l*-methylamphetamine and non-racemic mixtures with excess *l*-methylamphetamine in these two reports is perplexing. A method for extracting methylamphetamine from Vicks Inhalers (which in the US contain *l*-methylamphetamine) has been published in the 'underground' literature (Darth, 1977). However, it seems more likely that either *d*-ephedrine or *l*-pseudoephedrine, or a product containing one of these drugs, was inadvertently used as a precursor.

UK Seizures

For seizures submitted to the FSS it is not usually necessary to determine the salt form of a drug or to identify the particular stereoisomers of a drug. However, most amphetamine seized in the UK is probably *dl*-amphetamine sulphate made from phenyl-2-propanone, whereas most of the methylamphetamine seized in the UK is likely to be *d*-methylamphetamine hydrochloride made from ephedrine or pseudoephedrine. Purities quoted by the FSS are for the drug in the base form, not the salt form. Therefore, when comparing purities and doses for amphetamine and methylamphetamine it is important to bear in mind the differences between the hydrochloride, sulphate and base forms of the drugs and differences between the *d*-stereoisomer and the racemic *dl*- forms of the drugs.

Methylamphetamine gained popularity in the 1970's as it became known as a drug which gave a better 'high' than amphetamine. In the last quarter of 1975 the number of methylamphetamine cases showed a ten-fold increase compared to 1974 (1975a) and in early 1976 seizures of methylamphetamine hydrochloride were common place (1976a). By the end of 1977, amphetamine powder had been largely superseded in the illicit market by methylamphetamine (1977a). However, a year later, seizures of methylamphetamine powders had largely disappeared (1978a).

Methylamphetamine seizures again reached a peak in 1989 and since then availability has fluctuated (Stockely 1992).

Pharmaceutical products, such as "Bustaid" (Spanish slimming tablets) were often encountered as well as illicit products (e.g. 1973a).

In 1989, methylamphetamine accounted for 16% of all 'amphetamine' seizure records, but by 1992 this had declined to 1% (1993a). Until late 1997, this had declined to less than 0.1% (Hansard, 1999).

The number of police methylamphetamine seizure records[5] between 1995 and 2003 are shown in Figure 2. For comparison purposes, seizure data for amphetamine is shown in Figure 4. Methylamphetamine seizures peaked in 2001, with 256 seizure records representing over 10% of all 'amphetamine' seizure records. By 2003 the number of seizure records had declined to only 21, less than 1% of all 'amphetamine' seizure records.

Until late 1997, most seizures were powders (Figure 3) with typical purities of less than 10% (as base). The amounts seized are very small in comparison to the amounts of amphetamine seized Figure 5. Pure crystalline methylamphetamine hydrochloride ('ICE') was rarely seen in the UK.

The origin of the surge in tablet seizures in 1997-98 is unknown but information from the Netherlands suggested that the methylamphetamine had been synthesised by reductive

[5] Data from the FSS, Drugs Intelligence Unit database.

amination of phenyl-2-propanone using methylamine, hydrogen and a platinum catalyst. Impressions seen on the tablets included Windmill, Lips, Bird and the word 'ALADIN' (1998b).

For police seizures analysed between April 2001 and June 2004, there were over 350 seizure records for methylamphetamine. Almost 10% of these also contained amphetamine or 'ecstasy'. These were mostly powders and where measured, the average purity was about 9% (as base) with over 90% of powders having a purity of less than 15% (as base). Cutting agents, where identified, were mostly caffeine or glucose.

Most of the tablets bore a Mitsubishi logo and many also contained ketamine, ephedrine and caffeine. The drug content of the tablets is typically between 1 and 45 milligrams.

During this period, methylamphetamine was also encountered as an ingredient in over 50 'ecstasy' tablet seizure records and in over 80 amphetamine powder seizure records.

There were only 4 seizures described as 'ICE' and a further 5 seizures with purities greater than 70% (as base) which may have been 'ICE'.

Police seizures of ephedrine are generally low. Since 2001, the FSS has examined about 19 ephedrine powder seizures (total 13,884 grams) and about 397 tablet seizures (total 58,393 tablets). One of the powder seizures in 2001 comprised 13 kilograms of ephedrine powder. In 2001, Customs also seized a parcel containing 10 kilograms of ephedrine powder.

Figure 2: Methylamphetamine seizures examined by the FSS

(data for 1997 is estimated based on seizures between April and December)

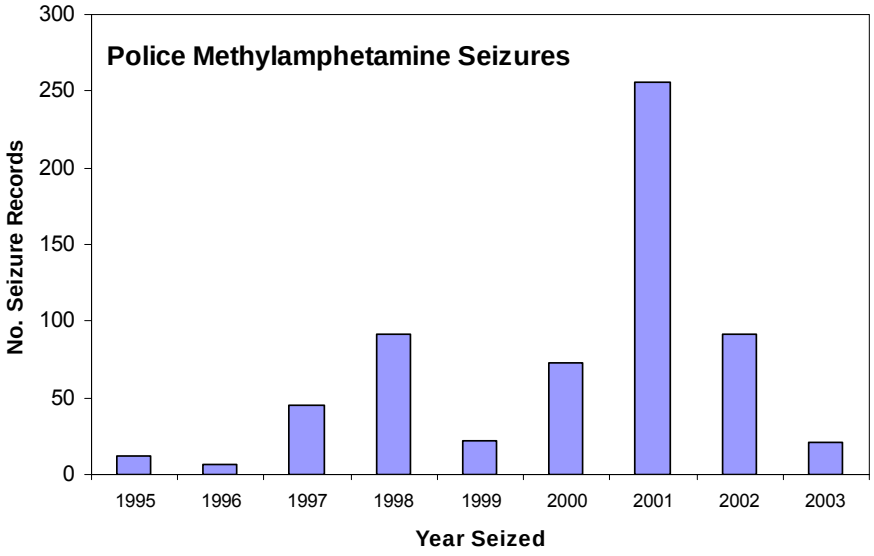


Figure 3: Police Seizures of Methylamphetamine Powders and Tablets

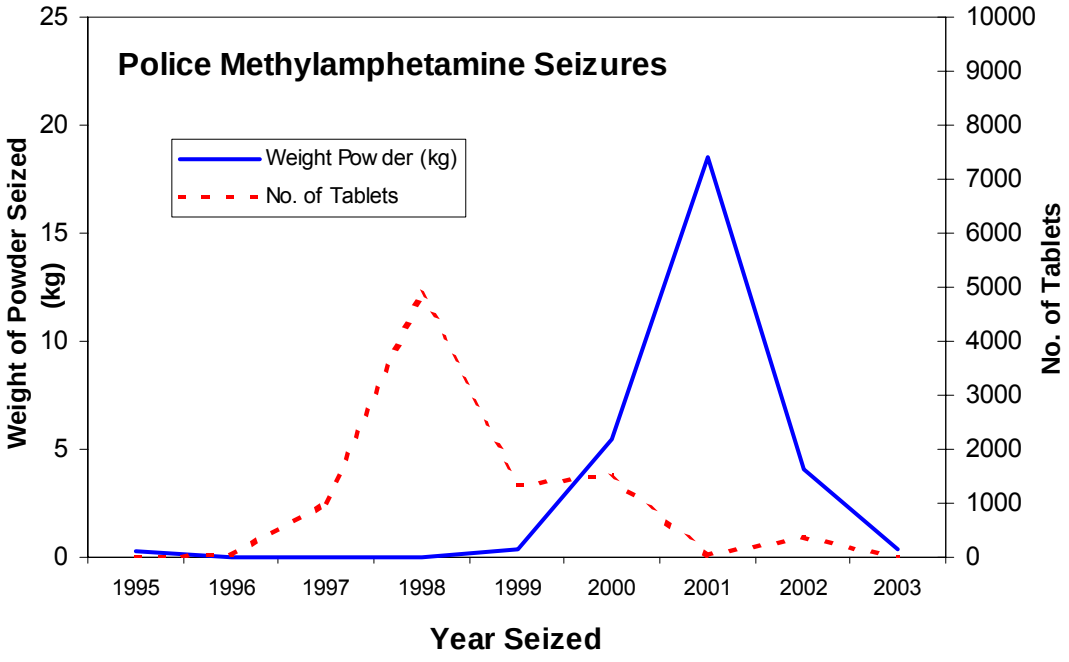


Figure 4: Amphetamine Seizures examined by the FSS

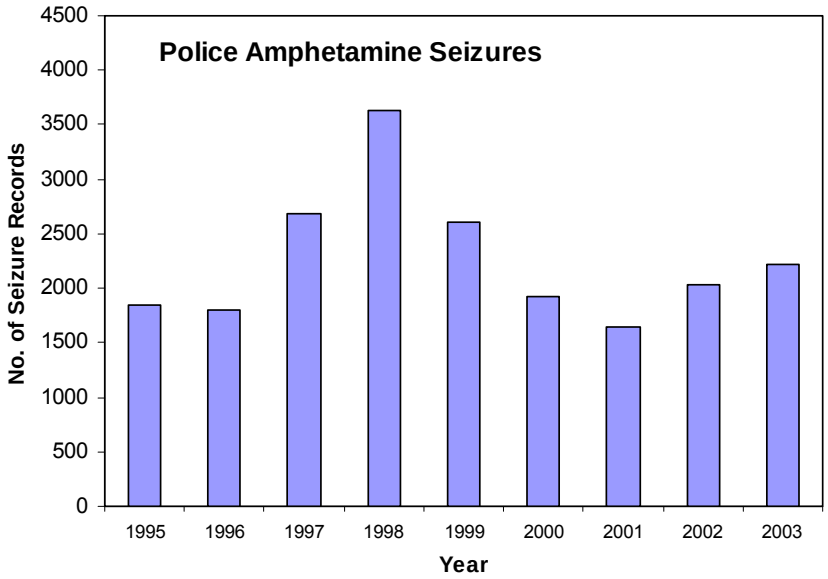
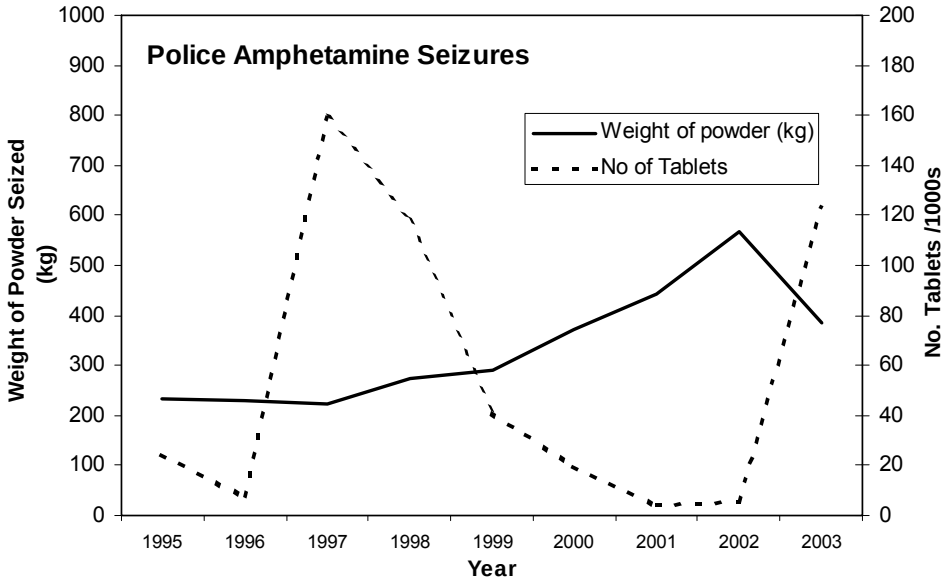


Figure 5: Police Seizures of Amphetamine Powders and Tablets



Toxicology Cases and Drug Driving cases

Detailed records are not available for these cases, but amphetamine is not uncommon. However, methylamphetamine is rarely encountered in toxicology and drug driving cases examined by the FSS and where it is detected the levels are not indicative of the drug being administered by smoking or injection.

In cases where both amphetamine and methylamphetamine are detected it is not usually possible to determine whether both drugs were taken or only methylamphetamine, as amphetamine is a metabolite of methylamphetamine.

The interpretation of results in toxicology cases is also complicated by the fact that methylamphetamine and amphetamine are metabolites of several other phenethylamine type drugs such as selegiline (Musshoff, 2000).

Importation into the UK

Since mid 1996, when Customs cases were first submitted to the FSS, there have been very few methylamphetamine seizures by HM Customs and Excise.

In 2000, Customs seized 1330 tablets bearing a butterfly design. The tablets contained approximately 32 milligrams of methylamphetamine (calculated as base).

For seizures examined between April 2001 and June 2004 there were only 5 customs seizure records.The largest was a seizure in March 2001 of 980 grams of powder with a purity of 9% (as base). There was one seizure of 1 gram of ‘ICE’ in 2001 and earlier this year a seizure of 21 grams of ‘ICE’.

In 2003, customs seized a postal package containing 8 small red tablets marked “wy”. These tablets match the description of those commonly referred to as “Ya-Ba”, and this is the first seizure of this type of to be analysed by the FSS. Tablets of this type are produced in South East Asia and usually contain 20-30% methylamphetamine hydrochloride and 60-70% caffeine together with starch, pigments and flavour components. The methylamphetamine is mainly prepared from ephedrine (or pseudoephedrine) using the Emde method (Puthaviriyakorn, 2002). Altho2 0 12 167.62767 ed 0 0 1fEMC /F

In the 3 years prior to 1969 the Bureau of Narcotics and Dangerous Drugs seized 95 illicit laboratories, 21 of which were producing methylamphetamine. These ranged in size from extensive, well-equipped laboratories to very crude operations (Gunn, 1970).

Methylamphetamine was most commonly produced by reductive amination of phenyl-2-propanone with methylamine and hydrogen using a palladium catalyst.

Amphetamine was also produced by the same method using hydroxylamine in place of methylamine.

Lithium aluminium hydride was also used in place of hydrogen and a catalyst.

Reduction of ephedrine with hydrogen iodide (hydriodic acid) or with hydrochloric acid and zinc or tinfoil were also reported.

Between 1978 and September 1981, the DEA seized 378 methylamphetamine laboratories and 68 amphetamine laboratories, Table 3 (Frank 1983).

Table 3: Illicit laboratories seized by DEA 1978-1981.

Laboratory Type	1978	1979	1980	1981*
Methylamphetamine	63	121	121	73
Amphetamine	13	20	23	12

* First three quarters

Forensic reports were available for 190 of the methylamphetamine laboratories. The most popular method (over 50%) was reductive amination of phenyl-2-propanone with methylamine, mercuric chloride, and aluminium metal in alcohol.

The next most popular method (less than 10%) involved the reaction of benzylchloride with magnesium to produce a Gringard reagent which, was then reacted with the product of an acetaldehyde/methylamine reaction. However, none of the 16 laboratories actually succeeded in producing methylamphetamine because of an error in an ‘underground’ publication.

The third most popular method (less than 10%) involved the Leuckart reaction of phenyl-2-propanone with methylamine and formic acid, or methylformamide.

Forensic reports were available for 37 of the 68 amphetamine laboratories and 75% of these used the Leuckart method, refluxing phenyl-2-propanone with ammonium formate or formamide.

In February 1980, phenyl-2-propanone became a Schedule II controlled substance in the US. This resulted in an increase in the number of laboratories synthesising phenyl-2-propanone, usually from phenylacetic acid. Illicit laboratory “chemists” also started to use other precursors, including benzylchloride and ephedrine (Frank, 1983).

In 1982 the reduction of ephedrine with hydriodic acid and red phosphorus started to become more popular (Skinner, 1990).

In 1989 the Birch method ("Nazi" method) for reduction of ephedrine with lithium (or sodium) in liquid ammonia was first encountered (Ely, 1990).

In 1989 there were 652 methylamphetamine laboratory seizures, representing 80% of all seized drug laboratories. Of these, 53% were using the ephedrine, red phosphorus and hydrogen iodide method to produce *d*-methylamphetamine and 47% were producing *d,l*-methylamphetamine from phenyl-2-propanone (Irvine, 1991).

In 1989 the DEA embarked on a broad chemical control program based on the Chemical Diversion and Trafficking Act (CDTA) of 1988. The CDTA was effective in reducing the supply of illicit methylamphetamine and the number of illicit laboratories seized in the first three years following its implementation, declined by 61% (2004f).

As a result of government controls, ephedrine and other chemicals used to manufacture methylamphetamine became more difficult to divert. Traffickers then began using over-the-counter capsules and tablets that contained these ingredients, as these products were exempted from the CDTA.

In 1993, the DEA participated in the seizure of 218 methylamphetamine laboratories. The ephedrine reduction method was used in 81% of these and phenyl-2-propanone was used in only 16% (Moore, 1996b).

In 1993 domestic chemical control was strengthened with enactment of the Domestic Chemical Diversion Control Act (DCDCA), which added a registration requirement for List I chemical handlers and established record keeping and reporting requirements for transactions in single-entity ephedrine products.

In 1993 hydriodic acid was added to the List 1 chemicals and hydriodic acid became virtually unavailable in the US. Illicit "chemists" then started to manufacture hydriodic acid or produce it *in situ* from iodine, water and red phosphorus (2003a).

Illicit laboratory "chemists" soon discovered that hydriodic acid could also be produced *in situ* from hypophosphorous acid and iodine (Massetti, 1996 and 2003a). The practice of using hypophosphorous acid in methylamphetamine production is believed to have begun when a methylamphetamine producer in Colorado obtained a recipe from Australia, where the hypophosphorous acid method was prevalent. The "chemist" then trained other producers and the method rapidly spread to other states (2003a).

BNMPA (α-benzyl-*N*-methylphenethylamine) is an impurity in methylamphetamine produced from illicitly manufactured phenyl-2-propanone from phenylacetic acid. In 1993-1994, a study of 80 urine samples, known to contain methylamphetamine, collected from drug rehabilitation programs, showed that only 2 contained BNMPA and/or its

metabolites. The findings are most likely due to the predominant use of ephedrine as a precursor at this time (Moore, 1996a).

When single-entity ephedrine products became regulated by the DCDCA, drug manufacturers turned to pseudoephedrine as a precursor. In California in 1995 there was a move towards the use of phenylpropanolamine to produce amphetamine rather than methylamphetamine using the red phosphorus method Kalchik, 1996).

In 1995, the proportion of illicit laboratories using pseudoephedrine as a precursor had increase from 1.5% in 1992 to 25% and incomplete data for 1996 showed that this had increased to over 38% (Wankel, 1996).

The Comprehensive Methamphetamine Control Act of 1996 (MCA) expanded regulatory control of lawfully marketed drug products containing ephedrine, pseudoephedrine, and phenylpropanolamine. Iodine also became a List II Chemical, with a 400 gram threshold.

In 1997 hypophosphorous acid and iodine were increasingly being encountered at illicit laboratories in California (Massetti, 1997). By 2001 the number of methylamphetamine laboratories using the iodine/hypophosphorous acid method had increased to 107 (2003a). The DEA have also seen several cases where phosphorous acid has been used as an alternative to hypophosphorous acid.

By the late 1990's only about 20% of the seized methylamphetamine laboratories were using the Birch ("Nazi") method (Cazenavette , 2000).

In 2001 the Methamphetamine Anti Proliferation Act of 2000 addressed the continuing diversion of pseudoephedrine and phenylpropanolamine drug products from the retail trade by reducing the threshold for such transactions from 24 grams to nine grams of pseudoephedrine or phenylpropanolamine base.

In 2001 red phosphorus, white phosphorus and hypophosphorous acid were added to the List 1 Chemicals.

Comments

The situation with regard to 'amphetamine' type drugs in the UK and the Netherlands is, at present, very different from that in the United States. However, this may change in the future and therefore it is important to have a better understanding of the reasons for these differences.

From a forensic science perspective, it is not clear why these differences exists, but methylamphetamine could become more prevalent, particularly in view of the following points:

1. Methods for the synthesis of methylamphetamine and amphetamine are widely available and the processes are similar.

2. Phenyl-2-propanone appears to be readily available in the Netherlands for the production of amphetamine and could therefore be used to produce methylamphetamine.
3. Customs have made some large seizures of ephedrine tablets in the UK *en route* to the United States and therefore it is likely that this precursor could easily be directed to production in the UK or the Netherlands.
4. Ephedrine and pseudoephedrine are available in the UK in over-the-counter medicines up to 60 milligrams per dosage unit and *Ephedra* plant products are available as herbal remedies.
5. The fluctuations in methylamphetamine seizures in the UK may be due to isolated sources of the drug, e.g. from a single illicit laboratory or from a single large importation of methylamphetamine. This suggests that there is a market for the drug when it is made available.
6. Methylamphetamine is considered to be more potent than amphetamine.
7. Methylamphetamine hydrochloride can be smoked whereas amphetamine sulphate is unsuitable for smoking.

On the other hand an increase in popularity of methylamphetamine is unlikely in view of the following:

1. There is very little illicit manufacture of synthetic drugs in the UK, possibly as a result of law enforcement activity and a high risk of detection.
2. Amphetamine sulphate is readily available in the UK so there is no incentive to import methylamphetamine or to synthesise it in the UK.
3. Amphetamine hydrochloride and amphetamine base (made from amphetamine sulphate and sodium bicarbonate) are probably viable alternatives to smokable methylamphetamine hydrochloride, but they have never been encountered in seizures in the UK.
4. Historically, methylamphetamine has been encountered in the UK for many years and since the 1970's has never become as popular as amphetamine.

Conclusions

1. Methylamphetamine is chemically similar to amphetamine, but field tests are available to discriminate between the two.
2. The number of methylamphetamine seizures in the UK has fluctuated over the last 15 years but has always been a small proportion of all 'amphetamine' type seizures. Most seizures are powders or tablets containing the hydrochloride salt, whereas amphetamine is usually encountered as the sulphate salt.
3. There have been very few seizures of 'ICE'.
4. In the United States the number of illicit methylamphetamine laboratories seized far exceeds the number of amphetamine laboratories.
5. Methods for the production of methylamphetamine are widely available and most are analogous to those for amphetamine.
6. Legislation affecting the availability of precursors in the United States has been a major factor in the choice of synthetic routes to methylamphetamine.
7. It is not clear why methylamphetamine hydrochloride is not prevalent in the UK, but it is important to realise that this may change in the future.

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